AGARD-R-809

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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD REPORT 809

POD Assessment of NDI Procedures Using a Round Robin Test

(les Tests comparatifs inter-laboratoires pour l'évaluation de la probabilité de détection (POD) des procédures NDI)

This report was prepared at the request of the Structures and Materials Panel of AGARD

NORTH ATLANTIC TREATY ORGANIZATION

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North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

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— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Exchange of scientific and technical information;

— Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

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Preface

At the 66th Meeting of the AGARD Structures and Materials Panel, held in 1988 in Luxembourg, a workshop was held on Nondestructive Evaluation (AGARD Report 768). This was the first of four workshops organized by the SMP on Damage Tolerance For Engine Structures. A paper was presented at that workshop by staff of the NRC Institute for Aerospace Research on "Importance of the Sensitivity and Reliability of NDI Techniques on Damage Tolerance Based Life Prediction of Turbine Discs" [1]. This paper presented the results of a demonstration project designed to establish the reliability and sensitivity of the non-destructive inspection methods commonly used by engine maintenance organizations in Canada to inspect gas turbine engine compressor discs. The results were surprisingly poor, and showed that the methods then employed were not able to support damage tolerance based life management of these components in a manner consistent with the stringent requirements laid down by MIL Standard 1783. Interestingly, this was one of the first, and possibly the first rigorous demonstrator project performed using real service exposed components containing service induced cracks. In contrast, many of the demonstrator projects performed to establish compliance with MIL-STD-1783 have been performed using laboratory prepared coupons containing laboratory induced cracks.

Several of the national representatives attending this 1988 workshop expressed interest in taking part in a similar demonstrator project so as to establish the reliability and sensitivity of the NDI methods available in their own countries. With the encouragement of the Structures and Materials Panel of AGARD, a second demonstrator project was organized. The results of this demonstrator project are presented in the following report. Clearly, the work has been especially useful to the laboratories that participated in the project since it has allowed them to compare and contrast their own results with those obtained in other laboratories and hence calibrate their own capabilities. In Canada it has provided some impetus to the development of fully automated eddy current systems with powerful signal processing and pattern recognition capabilities, but even these are being found to have unexpected limitations, and they need to be used with caution. These matters may be the subject of future AGARD-SMP reports. Apart from these direct benefits to the participating laboratories, the work has produced a substantial data base on the probability of detection of flaws in engine component inspection, and this data will be made available to the international community through the USAF supported Nondestructive Testing Information Analysis Center (NTIAC) of Austin, Texas, where it may be accessed electronically.

The work described in this report was performed on behalf of the Structures and Materials Panel of AGARD and with generous financial support provided by AGARD under the R&D Cooperation Program. This financial support allowed research staff of the four participating nations to make short working visits to the laboratories of the other countries.

The work carried out within each country has been performed with the help of many people who are not identified individually, but who are nevertheless most sincerely thanked. The work has also been supported by national authorities of each country who are acknowledged with gratitude. The following organizations of each country deserve special thanks.

Canada: Institute for Aerospace Research of the National Research Council of Canada, through IAR Program 3H3, Project JHU00. The Chief of Research and Development and the Directorate of Aeronautical Support Engineering, Department of National Defence.

Greece: Technology Research Center of Hellenic Air Force. Hellenic Aerospace Industry.

Turkey: The Welding and NDI Centre, Middle East Technical University. Lufthansa Airlines Maintenance Facilities, Hamburg.

Portugal: Air Force Academy, Portuguese Air Force.

W. Wallace
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Préface

On a pu assister, lors de la 66e réunion de la Commission des structures et des matériaux de l'AGARD (Rapport de l'AGARD, n° 768), en 1988, au Luxembourg, à la tenue d'un atelier sur l'inspection non destructive (IND). Il s'agissait du premier des quatre ateliers organisés sur la tolérance au dommage par cette commission. Des représentants de l'Institut de recherche aérospatiale du CNRC ont pu à cette occasion présenter une communication sur "l'importance de la sensibilité et de la fiabilité des techniques d'inspection non destructive dans les méthodes de calcul de durée de vie des disques de turbine fondées sur la tolérance au dommage (1)". La communication en question présentait le résultat d'un projet de démonstration visant à établir la fiabilité et la sensibilité des méthodes d'inspection non destructive utilisées au Canada par les ateliers d'entretien des moteurs pour inspecter les disques de compresseur. Ces résultats, étonnamment décevants, démontraient clairement que les méthodes utilisées n'étaient pas à même de répondre aux exigences rigoureuses des normes MIL-STD-1783 pour la gestion du cycle de vie des composants. Fait à noter, il s'agissait de l'un des premiers projets, et peut-être du premier projet de démonstration effectuée de façon rigoureuse, faisant appel à de vrais composants de turbine présentant des fissures survenues en cours de service. Dans plusieurs projets visant à démontrer la conformité aux normes MIL-STD-1783, on a utilisé par comparaison des échantillons préparés en laboratoire et contenant des fissures artificielles également produites en laboratoire.

Plusieurs représentants nationaux ayant assisté à l'atelier exprimèrent par la suite le désir de participer à un projet de démonstration similaire qui permettrait d'établir la fiabilité et la sensibilité des méthodes d'IND utilisées dans leurs pays respectifs. Un second projet fut donc mis sur pied sous l'égide de la Commission des structures et des matériaux. Les résultats qu'il a permis d'obtenir sont présentés dans le rapport qui suit. Les travaux exécutés ont été particulièrement utiles aux laboratoires participants du fait qu'ils leur ont permis de comparer et de contraster les résultats avec ceux obtenus par les autres laboratoires et, ainsi, d'étalonner leurs techniques. Au Canada, le projet a encouragé la mise au point de systèmes d'inspection à courants de Foucault entièrement automatisés avec fonctions de traitement de signal et de reconnaissance de spectre, mais dont les capacités ont révélé des limites inattendues, ce qui oblige à les utiliser avec prudence. Ce domaine pourrait donner lieu à de futurs rapports de la Commission des structures et des matériaux de l'AGARD. En plus de ces avantages directs dont ont bénéficié les participants, les travaux ont produit une banque de données substantielle sur la probabilité de la détection des défauts lors de l'inspection des composants de moteurs et ces données seront mises à la disposition de la communauté internationale par l'entremise du Non destructive Testing Information Analysis Centre (NTIAC) parrainé par l'USAF et situé à Austin, Texas, où les données seront accessibles électroniquement.

Les travaux décrits dans ce rapport ont été entrepris au nom de la Commission des structures et des matériaux de l'AGARD grâce à un apport financier généreux de l'AGARD dans le cadre du Programme de coopération en R et D. Cette aide financière a permis à plusieurs chercheurs de chacun des quatre pays participants d'effectuer de courtes visites de travail dans les laboratoires des autres pays affiliés.

Les travaux entrepris dans chaque pays ont fait appel à la participation d'un grand nombre de personnes dont le nom n'est pas mentionné individuellement mais que l'on remercie toutefois très sincèrement. Les travaux ont également été financés par les autorités nationales de chacun des pays participants qui ont toute notre reconnaissance. Nous tenons, enfin, à remercier tout spécialement les organismes suivants :

Canada : l'Institut de recherche aérospatiale (IRA) du Conseil national de recherches du Canada (CNRC), dans le cadre du Programme 3H3, Projet JHUOO, de l'IRA; le chef de la recherche et du développement et le directeur technique du soutien aérospatial du ministère de la Défense nationale

Grèce : le Centre de recherche en technologie de l'Armée de l'air grecque

Turquie : le Centre de soudure et d'inspection non destructive de l'Université technique du Moyen-Orient; les ateliers d'entretien de la Lufthansa, Hambourg

Portugal : l'Académie de l'Armée de l'air du Portugal

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Contents

POD ASSESSMENT OF NDI PROCEDURES USING A ROUND ROBIN TEST

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SUMMARY

Under the auspices of the AGARD Structures and Materials Panel R&D Cooperation Program, a round-robin NDI demonstration has been carried out. Six laboratories in four NATO countries participated in the project. The aim of the project was to determine the sensitivity and reliability of NDI procedures presently employed by the participating laboratories and to establish whether or not the procedures would be adequate for the implementation of a damage-tolerance based maintenance approach or whether improved methods are required.

In this demonstration, the bolt holes of several service-expired compressor disks and spacers from the J85-CAN40 engine were inspected using several NDI procedures including manual and automated eddy current, automated ultrasonics, X-ray, optical microscopy, liquid penetrant and magnetic particle inspections. Service-induced, low cycle fatigue cracks of various sizes were present in some of the bolt holes. After inspection, components were pry opened for verification of cracks. From the NDI and destructive test data, POD and lower 95% confidence curves as a function of crack size were determined for all techniques investigated and are described in this report.

1. INTRODUCTION

Components of aircraft engines are retired when they have reached a given number of operational cycles known as the "Safe Life Limit", which is based on an acceptably low probability of the formation of a detectable crack. However, the majority of parts at retirement still have useful life which will not be fully utilized. The costs and logistics associated with spare part replacement under the "safe life" maintenance philosophy are high. Therefore, the development of an attractive life management procedure that would allow continued safe use of components beyond the safe life limit is of interest to the air forces of several NATO countries. The foremost requirement known is that any new method must not jeopardize operational safety.

The U.S. Air Force has recently implemented a new maintenance philosophy known as "Retirement For Cause" (RFC) to extend the use of gas turbine engine parts beyond their original design safe life cycle. This is a result of the Engine Structural Integrity Program (ENSIP) as defined in MIL-STD-1783. The RFC approach is based on a "Damage Tolerance" (DT) design philosophy which assumes that all parts contain flaws. By using routine nondestructive inspections and fracture mechanics predictions, the DT approach ensures that the flaws will not grow to critical size during service.

Inspection, according to damage tolerance criteria, requires that the NDI procedures be quantified in terms of their sensitivity and reliability as defined by probability of detection (POD) and confidence limit measurements. The POD for NDI procedures can be assessed experimentally by inspecting statistically valid numbers of flawed and flaw-free parts using procedures that duplicate maintenance inspections. A comprehensive document describing testing and evaluation procedures for assessing the capability of an NDI system using POD and confidence limits has been published by AGARD [2]. The present work uses Reference 2 as a guideline to assess the NDI procedures employed by six laboratories from four NATO countries that participated in this demonstration project. The aim of the project is to determine the degree of reliability and the level of sensitivity of NDI procedures presently employed by the participating laboratories. The results of this study will be useful in determining whether or not the employed NDI procedures are adequate for the implementation of a DT-based maintenance approach, and therefore whether improved methods are needed.

2. EXPERIMENTAL MATERIALS AND METHODS

2.1. Test Components

The test components used in this study were service-expired compressor disks and spacers from the J85-CAN40 engine (Figures 1 and 2). Although, they were originally operated under the safe-life philosophy, these parts had remained in service beyond the safe-life-limit due to logistic problems with part replacement. A total of seven sixth stage compressor disks and six fourth stage spacers were employed. The disks and spacers are fabricated from precipitation hardened martensitic stainless steel (AM355). Each disk has 40 bolt

holes of 4.8 mm (0.188") diameter. Each spacer has two integral segments with 40 bolt holes in each segment of the same diameter as those of the disks. The thickness of the discs and spacers in the bolt hole region is 1.9 mm (0.075"). In service, these components are subject to low cycle fatigue, and as a result, cracks originating at the bolt holes were present in all the retired parts. Therefore only the bolt holes were inspected.

2.2. NDI Techniques and Procedures

A number of NDI techniques were used to examine the bolt holes of the test components. The techniques included liquid penetrant inspection (LPI), eddy current inspection (ECI), magnetic particle inspection (MPI), optical microscopic inspection (OMI), ultrasonic leaky-wave inspection (ULI) and X-ray inspection (XRI). Various combinations of these inspections were carried out at six different test establishments, on different subsets of the test components. The techniques and procedures employed are explained in further detail in the following paragraphs.

2.2.1. Liquid Penetrant Inspection

In general, the LPI method involves several steps as described in the following. First the parts are cleaned with a solvent, then they are soaked in a penetrant (fluorescent dye) for a period of time and subsequently washed to remove excessive dye from the surface. Emulsifier is then applied to bring out the penetrant trapped in the cracks and a developer is used to highlight the flaw under ultraviolet light. The parts are visually examined by an inspector (certified) under ultraviolet light and cracks are identified and measured. LPI can only indicate surface connected cracks and measure their size as seen on the part surface. The entire LPI process as well as the type of chemicals and dwell periods used are important in this inspection. Liquid penetrant inspection was carried out by five participating laboratories. Appendix A provides details of the chemicals and procedures used by each laboratory for LPI of the test parts. Most laboratories used a military or ASTM standard for their LPI process.

2.2.2. Magnetic Particle Inspection

Magnetic particle inspection is accomplished by inducing a magnetic field in a ferromagnetic part and applying either a dry magnetic powder or a liquid suspension of iron particles on the surface being inspected. Cracks cause local perturbations in the magnetic field which attract the magnetic particles producing indications visible by fluorescence under ultraviolet light. Surface connected or close-to-surface cracks can be detected and sized by an experienced operator. Important factors in the MPI are the magnitude and the direction of the applied magnetic field with respect to crack orientation. Three of the participating laboratories performed MPI on the test components and information on the procedures used is provided in Appendix A. These procedures were based on MIL-STD-1949.

2.2.3. Eddy Current Inspection

Principles of electromagnetic induction are used in eddy current inspection to detect surface and near surface flaws in electrically conductive materials. Inspections are done by bringing a coil (probe) carrying an alternating current close to the test material. In this way, an alternating magnetic field is induced in the material which generates a small current (eddy current). This eddy current, in turn, generates its own magnetic field which interacts with the magnetic field of the exciting probe. The presence of flaws interferes with the passage of the eddy current and changes the impedance of the coil which can be detected and measured. Instrument frequency, gain and threshold as well as the probe proximity to the material and crack geometry are some of the important considerations in this method.

The eddy current technique is widely used for the detection of fatigue cracks around fastener holes and many special probes and instruments with a range of capabilities, either manual or automated, are commercially available for bolt hole inspections. This method was employed by five of the laboratories that participated in the round robin tests using different instruments and procedures as described in Appendix A. Most of the laboratories used manual or semi-automated (with spinning probes) eddy current instruments, which are designated as ECI, and some also employed automated scanners with operator identifying defective bolt holes (ECI-A) or using pattern recognition to classify defective holes (ECI-AP).

2.2.4. Optical Microscopic Inspection

In this method, an optical microscope is used to inspect components for surface-breaking cracks. The surface finish, the crack opening and the crack surface length are important factors in the success of OMI. The geometry of the test components makes it difficult to examine the bore surface of the holes. Only one laboratory employed OMI as an NDI tool for detecting bolt hole cracks in this round robin exercise but no information on the procedure was provided.

2.2.5. X-Ray Inspection

This inspection is based on the differential absorption of X-rays by the material being inspected. Variations in the density, thickness and composition can cause variations in the intensity of the transmitted radiation and can be recorded on a sheet of film which appear as variations in shades of grey in the developed film. The location, size and orientation of cracks with respect to the X-ray beam as well as the material, thickness and procedures are important in the crack detection process. This method was used by only one laboratory and details of the procedure are given in Appendix A.

2.2.6. Ultrasonic Leaky-wave Inspection

The ultrasonic leaky-wave technique is based on the transmission of high frequency sound waves through a liquid medium (water) onto the surface of the test component at an oblique angle. This angle is selected such that the compressional waves, travelling in the liquid, are mode converted into surface waves in the test material. When the surface waves encounter sharp edges or cracks, they are partly scattered, "leaking" their energy back into the water which is picked up by a transducer and presented as an echo on a CRT. This echo is monitored during inspection, which is often performed in an automated ultrasonic C-scan system, and is recorded in a C-scan format. The surface waves interact with surface and near surface cracks which lie perpendicular to the propagation direction. Because of the rapid decay of the surface waves, reflections from edges or cracks can be well localized. The success of this technique depends on factors such as surface finish, crack size and orientation as well as the geometry of the test piece and the equipment setup. Only one laboratory employed the ULI method. More information on this technique can be found in Reference [3].

2.3. Destructive Crack Verification

After completion of all NDI, the existence of cracks in the bolt holes was verified by destructive testing. The destructive crack verification was carried out at IAR/NRC on every component except for three disks (No. D, F and G). These disks have not been returned to Canada. The crack verification process is schematically illustrated in Figure 3. First, approximately 2cm x 3cm samples were cut from the region surrounding each bolt hole using a laser cutting technique. Each sample was then sectioned into two pieces along the diameter of the bolt hole. In the inward piece (the larger section), a notch was introduced in the side opposite to the bolt hole and the sample was then pried open by closing the notch in a vice. The second piece was loaded in three-point bending until failure. In both cases, crack faces were under tension during loading. To monitor the pry opening process, the sections were examined periodically under an optical microscope to check the crack opening and if multiple crack sites existed. After pry opening, the fracture surfaces were examined under an optical or a scanning electron microscope (SEM) as required depending on the crack size. Under the microscope, the service-induced LCF cracks were easily recognized from the rupture failure due to their smooth and oxidized surfaces and the crack size was measured. The specimens that did not reveal a crack on the fracture surfaces were further examined on the bolt hole surface to make sure that a crack was not missed during the pry opening operation.

2.4. Statistical Analysis of Data

The results of NDI techniques used in this program consisted of three possibilities. A "hit" is when a crack exists and the NDI technique identifies the crack while a "miss" is when a crack exists but the NDI technique does not detect it. A "false call" refers to the case where a crack does not exist but the NDI method incorrectly indicates a crack. Hit or miss rates are defined as the number of cracks detected or missed over the total cracks present while the false call rate is the ratio of false calls to the total number of crack-free sites. The hit, miss and false call rates were found for each procedure. The inspection results were statistically evaluated in terms of probability of detection (POD) as a function of crack size (maximum length) and the 95% lower confidence bound on POD curve.

For POD analysis, values of 1 and 0 are given to "hit" and "miss", respectively. For "hit/miss" type data generated on the basis of one inspection per crack, either the log-normal or the log-logistic distribution can be used. A comparison of POD curves using these two distributions is made in Reference [9]. It has been recommended that the log-normal function be used for determining POD and confidence limits [2,9]. The mathematical functions underlying this distribution are described in the literature [e.g.2,4,5]. The functional form of the log-normal distribution is:

$$P_i = 1 - Q(z_i) \qquad \text{for } z_i = \frac{\ln(a_i) - \mu}{\sigma} \tag{1}$$

where $Q(z)$ is the standard normal survivor function, z_i is the standard normal variate, and μ and σ are the location and scale parameters of the POD curve. The location and scale parameters were estimated using the method of maximum likelihood estimators (MLE) as suggested in Ref. 2. The purpose of the MLE is to find estimates of the parameters that maximize the probability of obtaining the observed data. The following equation from Reference [2] was used.

$$L(P_i;\, a_i,\, x_i) = P_i^{x_i} \cdot (1 - P_i)^{1 - x_i} \tag{2}$$

where P_i is the probability of detection of crack size a_i and x_i is the inspection outcome; 0 for a miss and 1 for a hit. Further information on this procedure can be found in References [2,4 and 7] while details of the functions and computational procedures used in this program to calculate parameters and determine POD curves are provided in a separate document [8]. To determine the confidence bound on the log-normal POD curve, the method derived by Cheng and Iles [6,7] was used.

The existence of false calls in inspection data can bias a POD curve, because when false calls are high, a portion of the detected cracks are likely to be false indications at crack sites. In such cases, the inspection results are more correctly called probability of indication (POI) rather than probability of detection (POD), as the effect of false calls should be considered. Following the analysis described in Ref. 2, we define POI(a) as the probability of obtaining an indication of a crack at crack length a, POD(a) the probability of correctly detecting a crack at crack length a, and p as the probability of false indication or the false call rate. It is assumed that p is independent of crack size. The relationship between these variables can be written as:

$$POI(a) = p \cup POD(a) - p \cap POD(a) \tag{3}$$

which states that the POI is given by the sum of the false calls p and the correct indications POD, minus the overlap where both occur together. This can be expanded to:

$$\begin{gathered} POI(a) = p + (1 - p)\ POD(a) \\ \text{or} \\ POD(a) = \frac{POI(a) - p}{(1 - p)} \end{gathered} \tag{4}$$

Statistical methods in the literature for finding POD(a) usually give results for POI(a), and assume a small false call rate. It can be seen that for a small false call rate, the POI(a) will be a good representation of the POD(a). Reference 2 suggests a maximum false call rate of 5% (or $p = 0.05$) to ensure an accurate modelling of the true POD. In this work, both POI and POD curves as well as the 90/95% values on POI and POD were calculated for all inspections. For inspections with less than 5% false calls, the POI and POD curves overlap, therefore, only the POD curve is shown. For inspections with false call rate greater than 5%, both POI and POD curves are presented.

To have a better estimate of the true POD, it is possible to calculate the POD at any crack length from the POI, and then use this calculated POD to estimate the parameters defining the log-normal curve which best models the POD curve. This allows the use of the Cheng and Iles [5,6] method of obtaining confidence bounds on the estimate of the true POD curve.

The crack length at a 90% POD level and 95% confidence ("90/95%" length) is often used as the initial flaw size in the damage tolerance-based design and maintenance approach. Therefore, the 90/95% crack length values were used as a simplistic way of comparing different NDI procedures. It must be pointed out that not all of the inspections were carried out on the same set of components, since some laboratories performed inspections on a limited number of components, however, comparison of the data from different sets is reasonable considering that the materials and bolt hole geometries were nominally identical. Also, it must be mentioned that the POD data presented in this report are based on the results of inspections performed during the present investigation and cannot be generalized for every procedure or component. If any of the variables involved in each NDI process (e.g. operator, instruments, settings, component, flaw types, etc.) are altered, it is expected that the POD data will be different.

3. RESULTS

3.1. Inspection Data

Table I identifies components that were inspected at each test site. The complete inspection data is presented in tabular form in Appendix B. Each table contains all the NDI and destructive test results for one component. Inspection results provided by the participating laboratories are listed for different techniques with "h" indicating a hit, "m" representing a miss and "f" indicating a false call. These allocations are based on the outcome of destructive tests which are also presented along with the crack size (maximum length and total area), the number of cracks in each bolt hole and the location of the largest crack. In the case of multiple cracks, only the largest one was considered in the analysis. No attempt was made to evaluate the performance of the NDI procedures in terms of inspection time, cost, simplicity, or their ability to estimate the crack size .

3.2. Crack Profiles

Destructive tests and examination of fracture surfaces indicated that most cracks initiated near the edges of the holes and formed corner cracks. Often, initiation occurred at the bore of the holes and grew radially inward towards the centre of the component. There were cracks which did not touch the top or bottom surfaces and these were termed middle cracks as well as cracks which touched both surfaces and were referred to as through cracks. Examples of different crack types are provided in Figures 4 and 5. Figure 6 provides the distribution of different crack types as a function of crack length indicating that the majority of cracks were small (less than 0.5 mm in length) corner cracks. Most holes had a single crack but multiple cracks, as many as seven, were also seen in many holes. Some cracks did not occur along the radii of the discs; many of these were initiated at what appeared to be voids or inclusions in the material and were often accompanied by larger cracks on the radii. Some totally internal cracks as well as outward propagating cracks were also seen.

The shape of cracks varied depending on their location; middle cracks were mostly semi-elliptical, corner cracks appeared as a quarter of an ellipse and through cracks were close to rectangular in shape. A combination of the above shapes was often seen in the case of multiple cracks. The crack size was measured in terms of total area of crack face and the maximum length. In cases where failure did not occur through a crack, the bore surface of the bolt hole was examined and if a crack was found, the crack length at the surface was measured.

3.3. Statistical Analysis

Table II contains a summary of the test results which compare the performance of the different NDI procedures used at the participating test sites. The number of bolt holes inspected by each procedure is given along with the total number of cracks in the population as identified by destructive crack verification tests. Also, the number and percentage of cracks detected (hit), missed or incorrectly identified (false calls) as well as the 90/95% crack length on POI and POD are provided.

Figure 7 shows histograms of the percentages of cracks missed by each inspection procedure, organized by crack type. Through cracks were the easiest type to detect by all techniques, because they were generally larger and open to surfaces. However, only eddy current inspection was able to detect more than 90% of through cracks. Middle cracks were the hardest to detect for all methods, mainly because these cracks were mostly small and it was physically difficult to access or view the bore surface of the holes. There were a large number of small (<0.5 mm) corner cracks which were missed by all methods. In all cases, the eddy current inspections were the best performers.

Probability of detection relationships to crack length are shown in Figures 8-25 for the NDI procedures used in this program. The figures show the actual inspection results, 1 for a detection and 0 for a miss, the mean POD and POI (if false call rate> 5%) as well as the 95% lower confidence curves on POI and POD calculated using the log-normal distribution with the method of maximum likelihood estimators. Note that false calls are taken into account in the POD but not in the POI curves. The false call rate for each NDI procedure is also shown on the graphs.

3.3.1. Probability Data for Liquid Penetrant Inspections

The false call rates for liquid penetrant inspections were less than 3% and therefore only the POD curves are shown in Figures 8-12. The LPI POD results of different organizations were very similar with the exception of organization VI which was different. The LPI data of this laboratory obtained on 160 bolt holes, which happen to contain only small (<2 mm) cracks, showed only a 11% detection rate with no false calls. The other four laboratories had detection rates of 25-28% and false call rates of 0.9-2.6%. Despite the low detection rate for that one test site, at 1.9 mm, the 90/95% crack length was less than those for the LPI processes of the other four laboratories which had 90/95% values in the range of 2.7-3.7 mm. These are close to the values obtained in the earlier investigation using similar disks [1,9] implying that the LPI results can be very reproducible if the procedure remains similar. The lower 90/95% crack length for organization VI could be attributed to the small sample population used by that test site and the fact that there were no missing cracks larger than 1.8 mm in their data base. With the exception of a 4.6 mm crack which was missed by the laboratory I, all cracks larger than 2.6 mm were detected by the LPI procedures employed. Since the LPI method relies on penetration of a liquid into cracks, the tightness of cracks may have contributed to missing a large number of small cracks.

3.3.2. Probability Data for Magnetic Particle Inspections

Magnetic particle inspections were performed at three facilities on three different subsets of the sample population. The MPI tests achieved detection rates of 26-35%, 90/95% values of 1.9-3.7 mm and false call rates of 0-10.5%. The largest crack missed by these inspections was in the 1.6-4.6 mm range. These numbers and the POD curves (Figures 13-15) indicate that the MPI and LPI procedures produced similar results for the test components of this exercise. Comparison of the MPI results for these three laboratories clearly indicate that organization I has achieved zero false calls at the expense of missing a large number of small cracks while Organization III has detected a larger number of small cracks but produced a high false call rate. In this case, a portion of the detected cracks are likely to be false indications at crack sites which are not reflected in the POI but are considered in the POD data.

3.3.3. Probability Data for Eddy Current Inspections

Figures 16-22 show POD/POI curves for ECI procedures. Except for Organization I which had a relatively low detection rate of 28% and a high 90/95% value of 2.64 mm, the ECI results for all other laboratories were similar and the detection rates were in the range of 47-79% and the 90/95% values in the range of 0.84-1.8 mm. The false call rate for that one laboratory was also very low (0.87%) as compared to the others (3.4-12.5%). This implies that this particular inspection may have been done using less sensitive instruments or settings (e.g. high threshold level), therefore, a large number of small cracks have been missed. The largest crack missed by the ECI procedure varied from one laboratory to another and was in the range of 1.1-4.6 mm.

In addition to manual eddy current inspections (ECI) which were used by all test sites, one of the laboratories also performed inspections using an experimental automated system with pattern recognition capability using a non-contact spinning probe. Automated eddy current inspections were performed and the signals were stored. The eddy current signals were interpreted both by an operator (ECI-A) as well as by pattern recognition technique as designated by ECI-AP. In contrast to what was expected, neither automated inspections nor the pattern recognition analysis achieved any better results than those of the manual inspections. The subsequent analysis of the automated ECI signals indicated that on many occasions during inspections, the eddy current probe had touched the bore of the bolt holes producing false indications. While the result of automated ECI was somewhat disappointing, nevertheless it illustrated that automation of inspections may not necessarily provide better results unless the equipment is properly designed and set up for specific inspections. Overall, eddy current procedures produced the best POD results among the techniques investigated in this exercise.

3.3.4. Probability Data for Optical Microscopic and X-Ray Inspections

These inspections produced low false call rates but missed a large number of cracks as seen in the POD data (Figures 23,24). The largest cracks missed were 6.6 mm for the optical technique and 5.3 mm for the X-ray method. The 90/95% crack length found for the optical method was 26.7 mm and for the X-ray technique was 16.5, indicating that these methods are not appropriate for detecting LCF cracks in engine components of the type investigated here. The OMI inspections suffer because of the component surface roughness, tightness of cracks and the difficulty in viewing the bore surface. X-ray inspections of these components are also difficult, due to component material and geometry and the small crack sizes.

3.3.5. Probability Data for Ultrasonic Leaky-wave Inspection

Although an attempt was made to inspect all components using the ultrasonic leaky-wave approach, only results for the disks were considered complete since the geometry of the spacers did not allow inspection of inner surfaces by this method. Therefore, only the data for disks were analyzed and the POD curves are shown in Figure 25. The false call rate was 1.4%, the largest crack missed was 1.8 mm and the 90/95% crack length was 2 mm. These results are very similar to those obtained in the previous investigation using similar disks [1,9].

4. EFFECT OF FALSE CALLS

If noise is present in the response signal, false indications can result if noise response from a crack-free site is interpreted as being caused by a crack. False calls are undesirable for economic reason, but often there is a trade off between the false call rate and the ability to detect small cracks. As shown by the POI and POD curves as well as the associated 90/95% crack length values, for a given inspection procedure, high false calls only marginally improve the chance of identification of cracks. However, the true probability of detection (POD) decreases more with increasing false calls as illustrated in Figure 26 for a typical inspection with a 90% true POD and no false calls. This indicates that every inspection process has a certain detection limit indicated by the signal-to-noise ratio which is governed by many factors including the physics of the procedure, instruments and settings employed, signal processing methods, the test material and geometry, the operator, etc. Hence, any attempt to increase the number of hits by such means as using high instrument gain or low threshold level and deliberately identifying noisy signals as cracks without improving the signal-to-noise ratio will only marginally increase the probability of indication but not the true probability of detection.

5. MULTIPLE INSPECTIONS

The purpose of repeated inspections is to increase the POD. The POD calculations for double inspection are provided in Ref.[2]. We attempted to combine the data from two inspections of the same or different techniques. The resulting POD curves indicated improvements when the two procedures were different and some of the cracks missed by one inspection were picked up by the second one. However, in many cases the inspection which had the higher hit rate had picked up almost all the cracks that the second one detected and therefore the combined POD remained unchanged.

6. CONCLUSIONS

The bolt holes of seven compressor disks and six spacers from the J85-CAN40 engine were inspected by a number of NDI procedures at different test sites. Four of the disks and all of the spacers were sectioned destructively to verify the presence of cracks and to measure crack size. Based on the NDI and destructive results, the probability of indication and the probability of detection relationships with crack size were found for each procedure using the log-normal distribution with maximum likelihood estimators. The POD data was used to evaluate different NDI procedures in terms of sensitivity and reliability.

Among the techniques investigated, eddy current procedures had the highest sensitivity and reliability in detecting LCF cracks in these specific components as indicated by the POD-crack size relationships and the crack sizes detectable at 90% POD with 95% confidence level. Automation of this procedure, in terms of inspection or signal interpretation, may improve the results only if the system is designed and operated properly. Ultrasonic leaky-wave POD results were also comparable to the ECI. Liquid penetrant and magnetic particle inspections produced similar POD results on the components but LPI results appeared to be more reproducible. X-rays and optical microscopic inspections did not detect the majority of cracks and are considered inappropriate for application to engine parts of the type investigated.

False calls only marginally increase the probability of indication but not the true probability of detection. To improve the POD, signal to noise ratio should be increased. Combining data for the best and worst of the same technique resulted in POD improvement in the case of LPI and MPI methods but no change for the ECI technique. Benefits from repeated inspections are realized only when the two procedures are different and some of the cracks missed by one inspection are picked up by the second one.

Damage tolerance criteria, based on the U.S. Air Force MIL STD 1783, requires repeatable detection of cracks with characteristic dimensions less than 0.5 mm at 90% POD and 95% confidence. If this criteria is to be applied to the NDI procedures investigated, none of the inspections are adequate for damage tolerance application. Eddy current procedures have the most potential to achieve such requirements if further improvements are made in the signal-to-noise ratio.

7. REFERENCES

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Table I Summary of disks and spacers that were investigated by different inspection techniques at the indicated organizations.

Technique	LPI					MPI			ECI					ECI-A	ECI-AP	OMI	XRI	ULI
Organization	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV
Component																		
disk A	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
disk B	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
disk C	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
disk D	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
disk E	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
disk F	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
disk G	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
spacer H1		x	x				x	x		x	x			x	x			
spacer H2	x	x		x	x	x	x		x		x		x	x	x	x		
spacer I1		x	x				x	x		x	x			x	x			
spacer I2	x	x		x		x	x		x		x			x	x			
spacer J1		x	x				x	x		x	x			x	x			
spacer J2	x	x		x	x	x	x		x		x		x	x	x	x		
spacer K1		x	x				x	x		x	x			x	x			
spacer K2	x	x		x	x	x	x		x		x		x	x	x			
spacer L1		x	x				x	x		x	x			x	x			
spacer L2	x	x		x		x	x		x		x			x	x	x		
spacer M1		x	x				x	x		x	x			x	x			
spacer M2	x	x		x	x	x	x		x		x		x	x	x	x		

An "x" in the appropriate box indicates that the inspection indicated was performed on that component.

Table II A summary of the inspection results.

Technique	LPI					MPI			ECI					ECI-A	ECI-AP	OMI	XRI	ULI
Organization	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV
holes	400	640	400	400	160	400	640	400	400	400	640	160	320	640	640	320	160	160
cracks	285	404	207	285	134	285	404	207	285	207	404	88	222	404	404	222	88	88
hits	73	101	52	79	15	73	140	61	79	134	236	70	150	231	193	39	26	44
rate (%)	26	25	25	28	11	26	35	29	28	65	58	80	68	57	48	18	30	50
misses	212	303	155	206	119	212	264	169	206	73	168	18	72	173	211	183	62	44
rate (%)	74	75	75	72	89	74	65	82	72	35	42	20	32	43	52	82	70	50
false calls	1	2	5	1	0	0	11	20	1	19	8	9	10	26	20	0	2	1
rate (%)	0.87	0.85	2.6	0.87	0.00	0.00	4.7	10.4	0.87	9.8	3.4	12.5	10.2	11.0	8.5	0.00	2.8	1.4
90/95 length (mm)																		
POI	3.60	2.65	3.21	3.56	1.90	3.70	1.95	3.15	2.64	1.06	1.17	1.34	0.81	1.43	1.74	26.6	16.5	2.03
POD	3.60	2.66	3.24	3.58	1.90	3.70	1.98	3.28	2.64	1.12	1.19	1.40	0.84	1.51	1.80	26.6	16.6	2.03

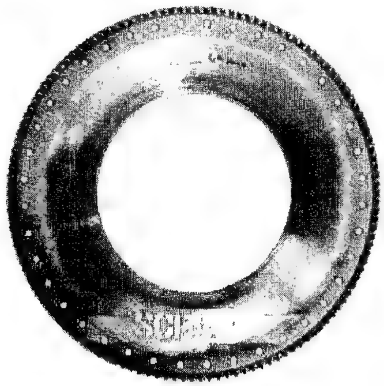


Figure 1. A compressor disk of the type used in this study.

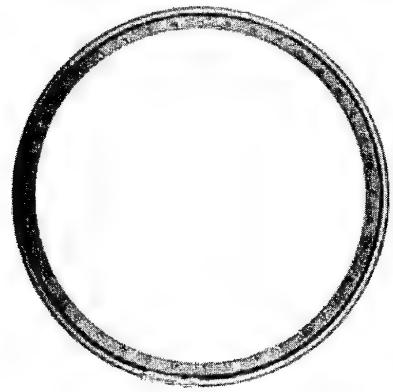


Figure 2. A compressor spacer of the type used in this study.

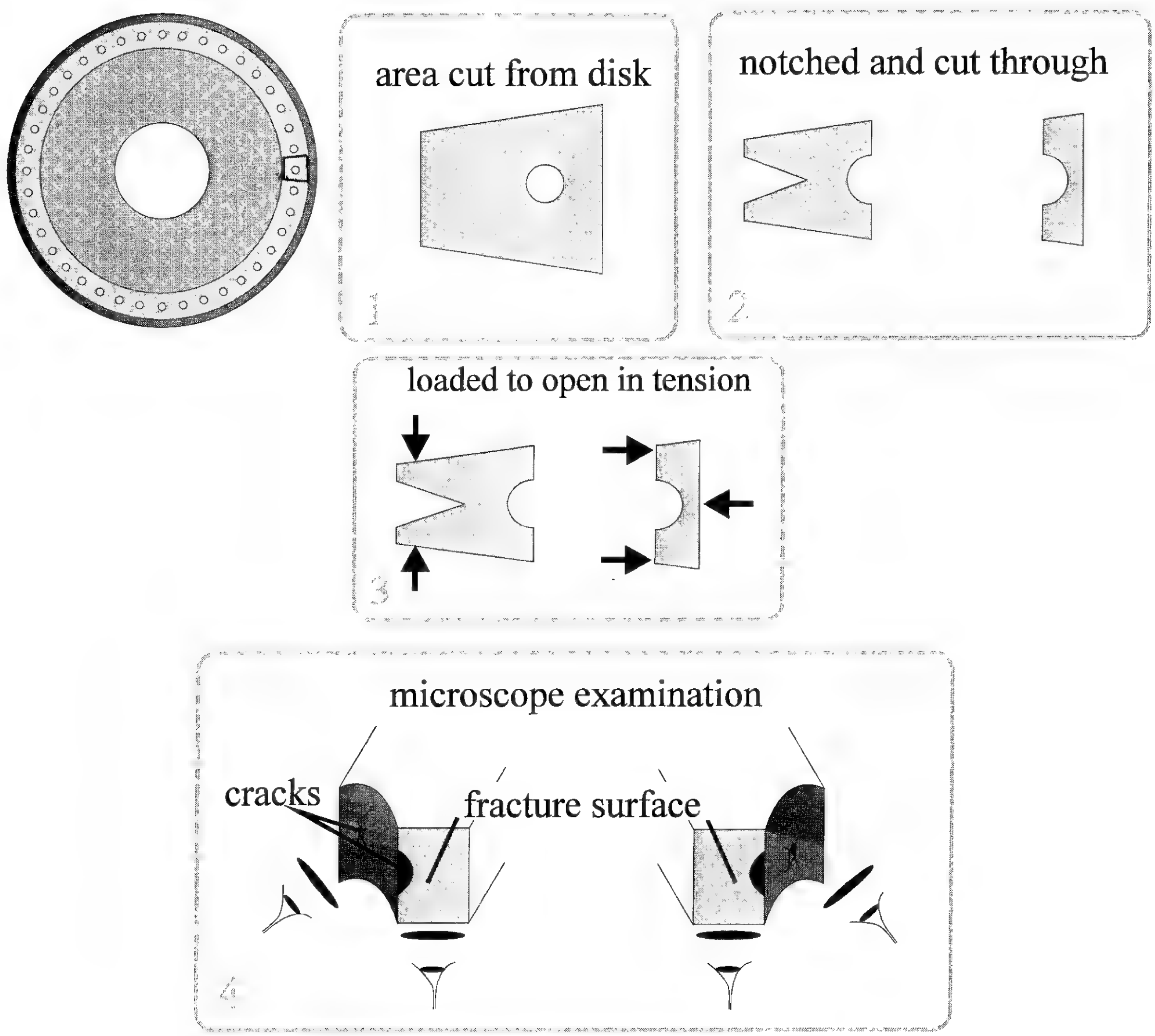
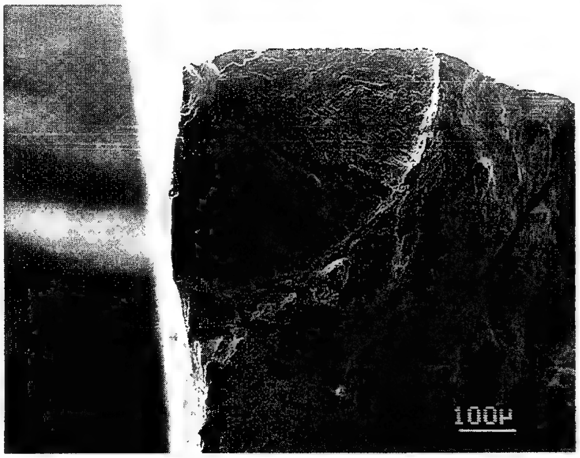
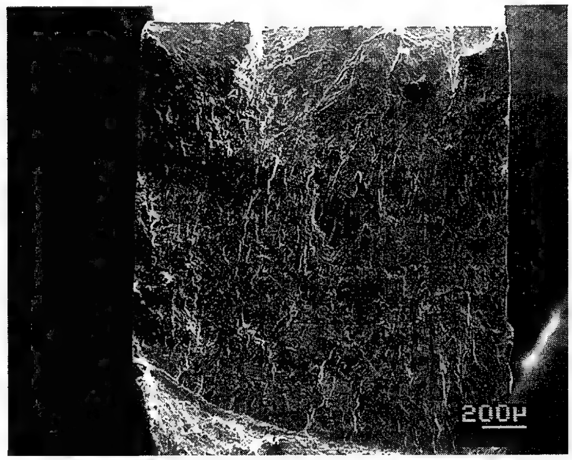


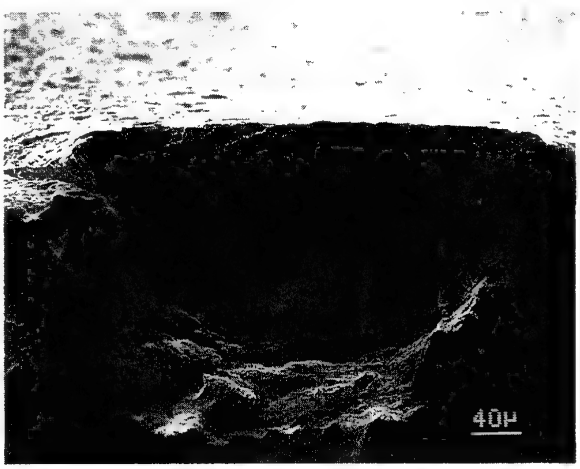
Figure 3. Schematic illustration of sectioning, pry opening, and microscope examination of bolt hole specimens.



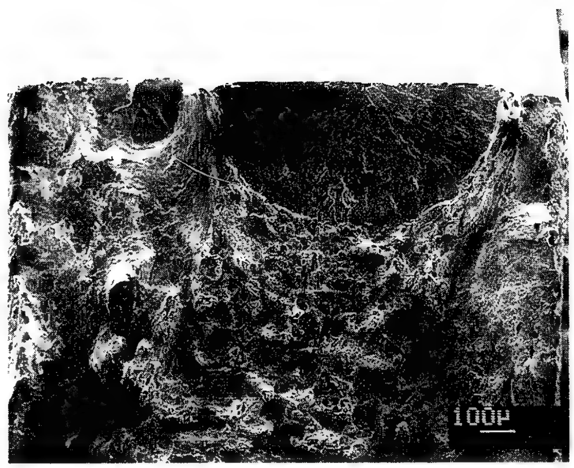
a) A corner crack



b) A through crack



c) A middle crack



d) A multiple crack

Figure 4. Examples of different crack types in the bolt holes

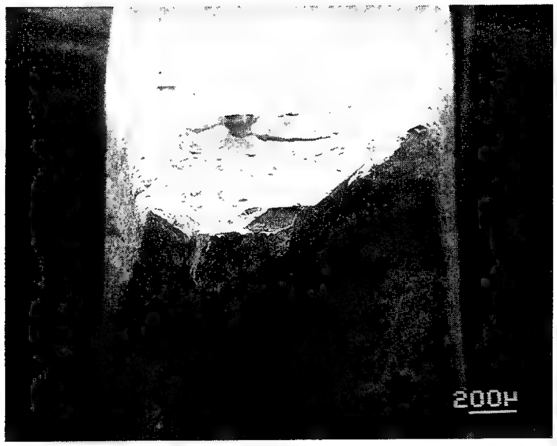


Figure 5. a) A small crack in the bolt hole bore

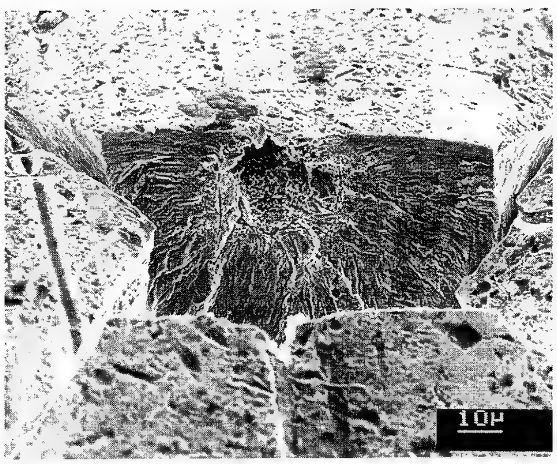


Figure 5. b) A crack initiating cavity

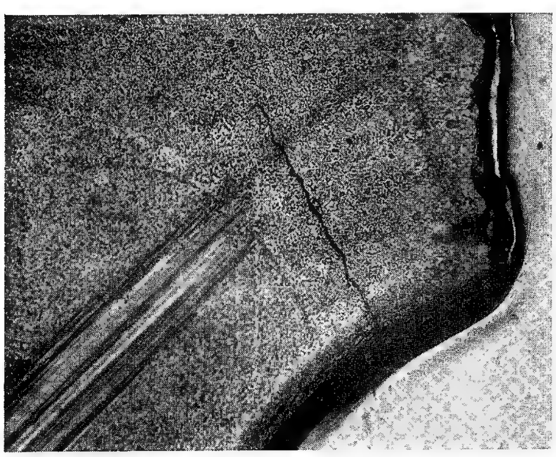


Figure 5. c) A cellulose-acetate replica of the disk surface, showing a crack

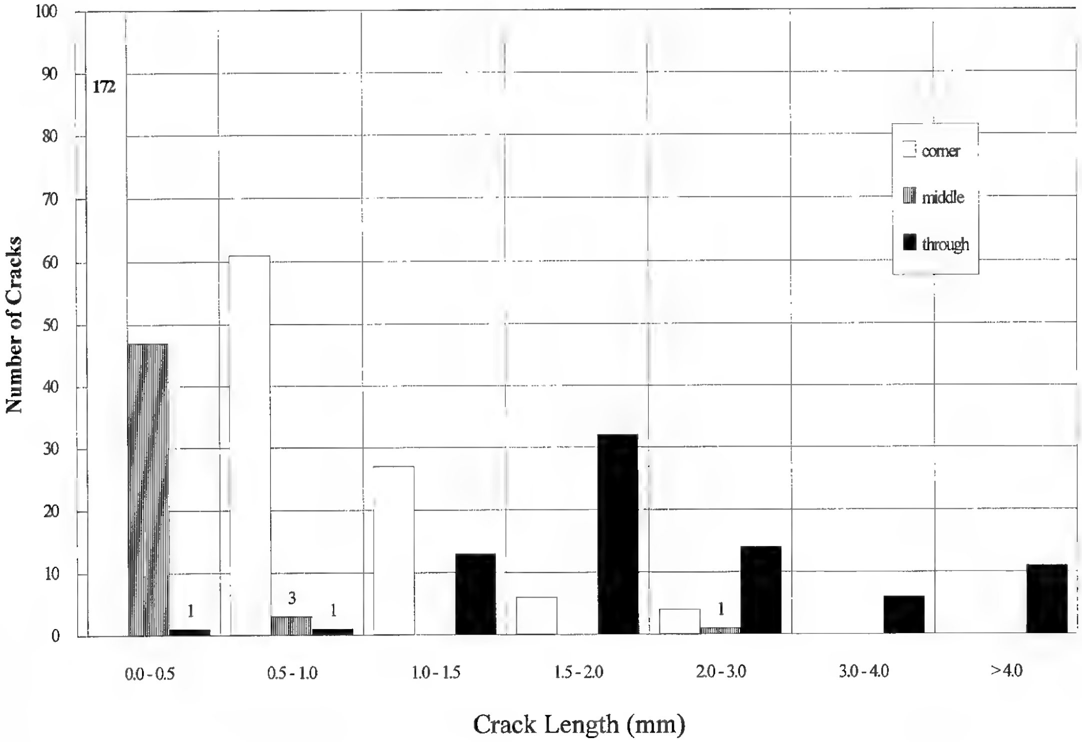


Figure 6. Histograms showing the distribution of crack types as a function of crack length

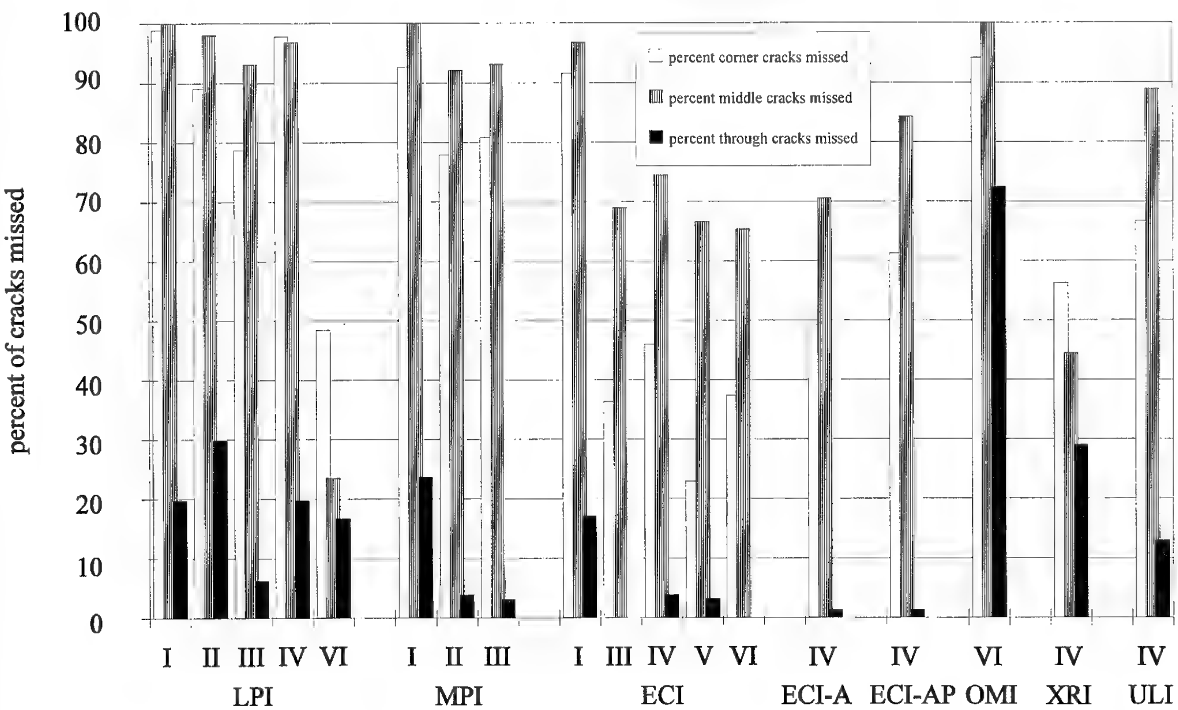


Figure 7. Histograms of percentage of cracks missed for each crack type, by each inspection procedure

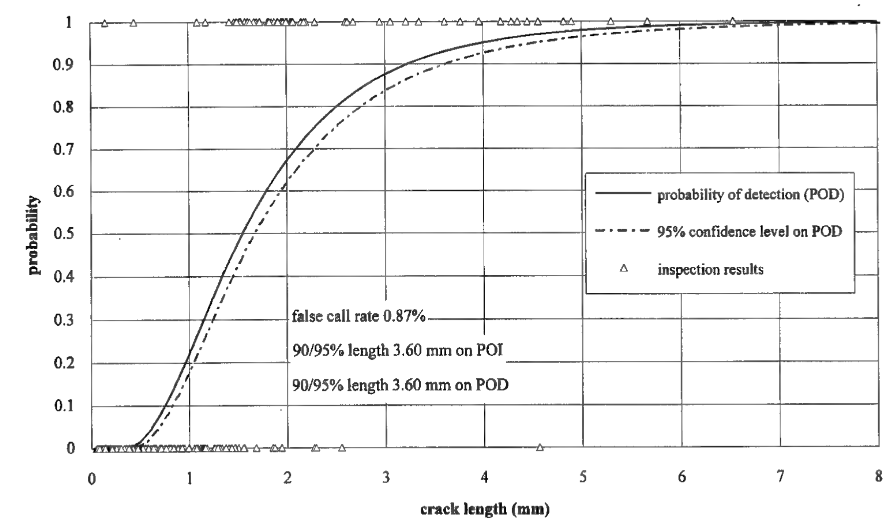


Figure 8. Dependence of POD on crack length, LPI organization I

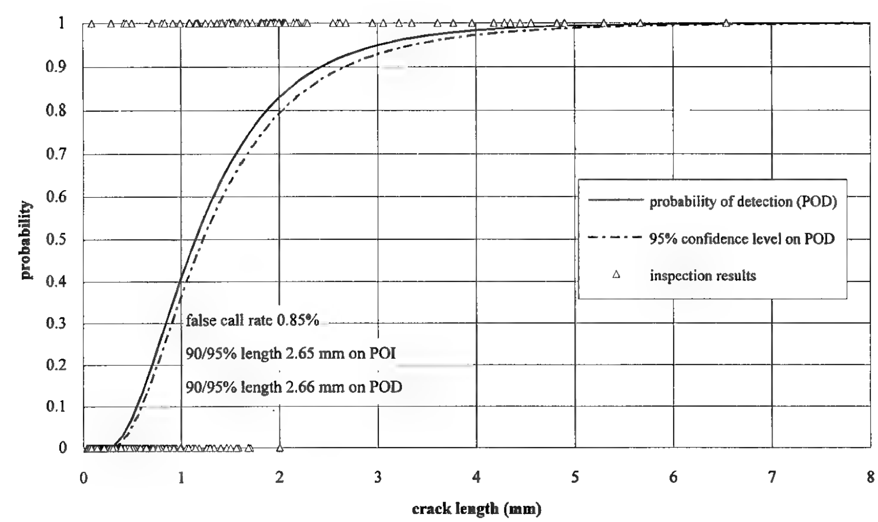


Figure 9. Dependence of POD on crack length, LPI organization II

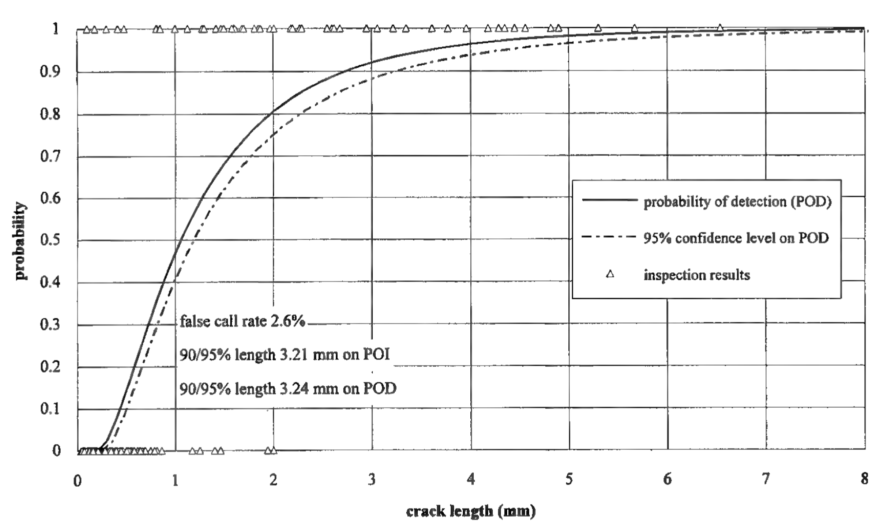


Figure 10. Dependence of POD on crack length, LPI organization III

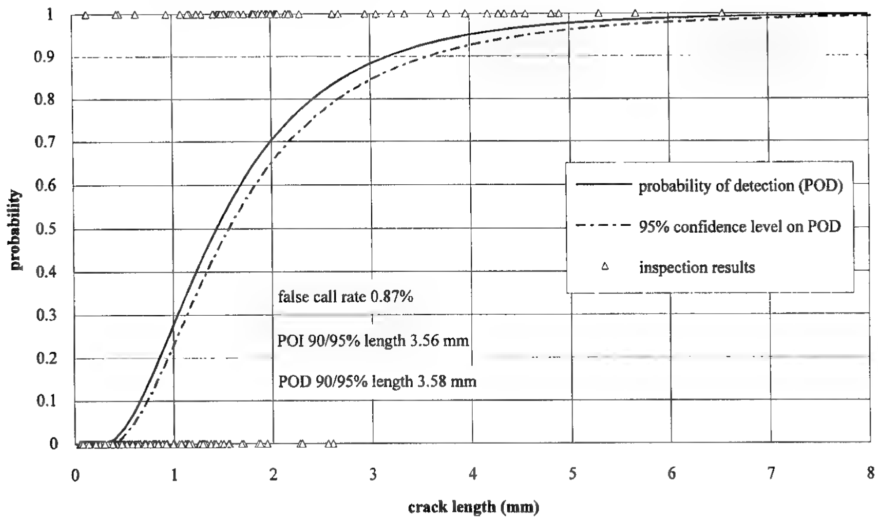


Figure 11. Dependence of POD on crack length, LPI organization IV

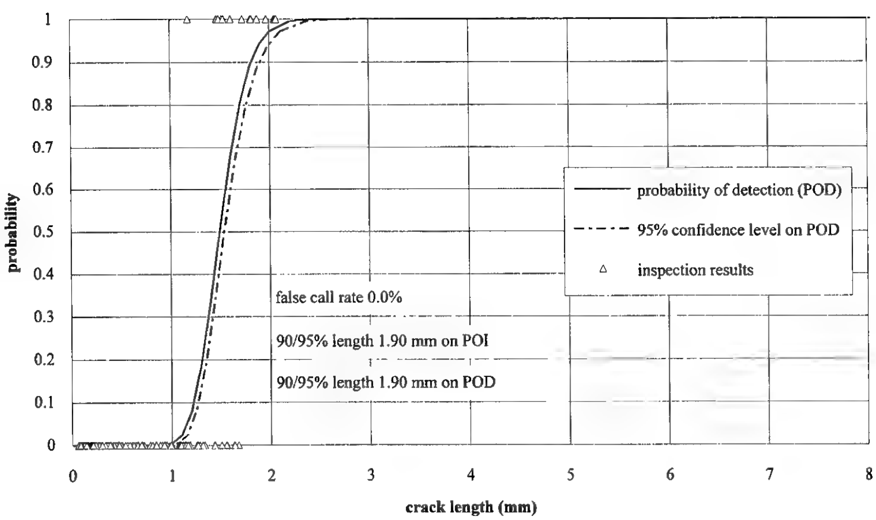


Figure 12. Dependence of POD on crack length, LPI organization VI

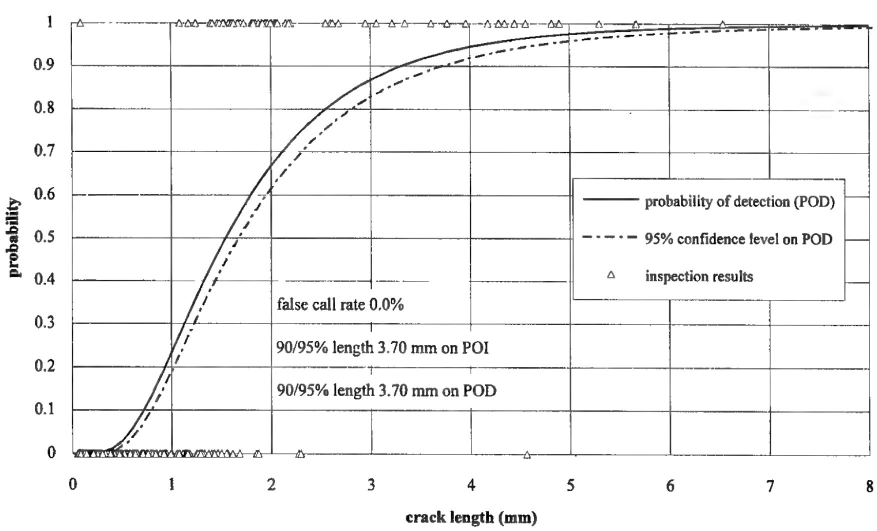


Figure 13. Dependence of POD on crack length, MPI organization I

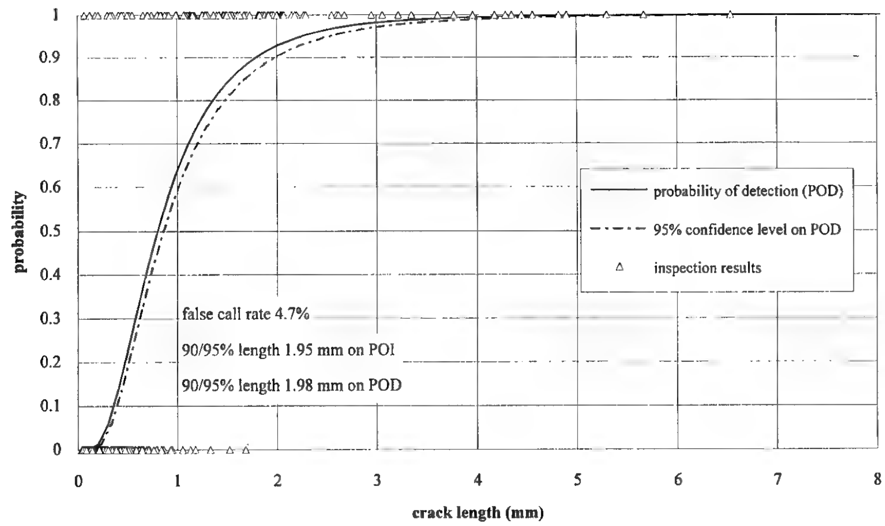


Figure 14. Dependence of POD on crack length, MPI organization II

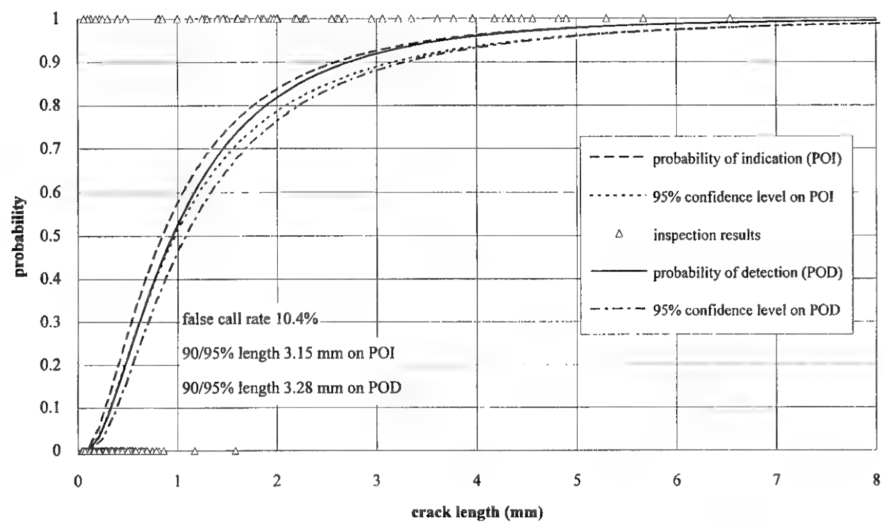


Figure 15. Dependence of POI and POD on crack length, MPI organization III

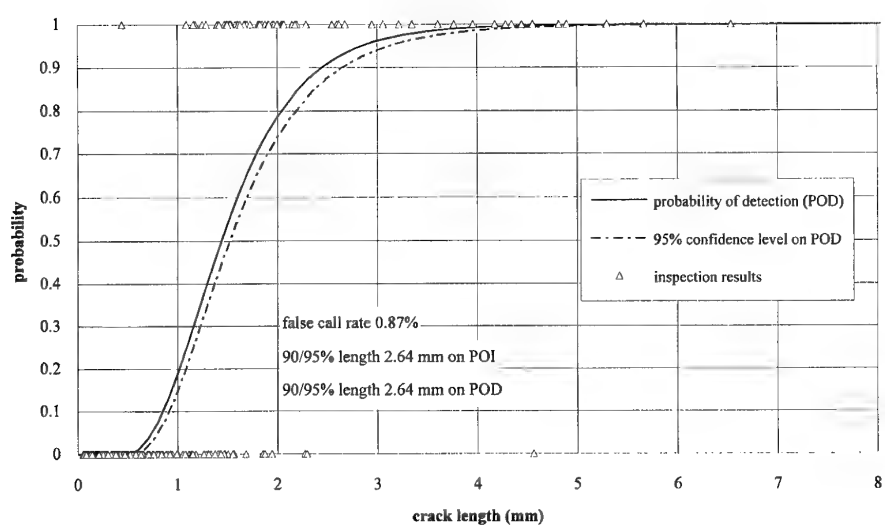


Figure 16. Dependence of POD on crack length, ECI organization I

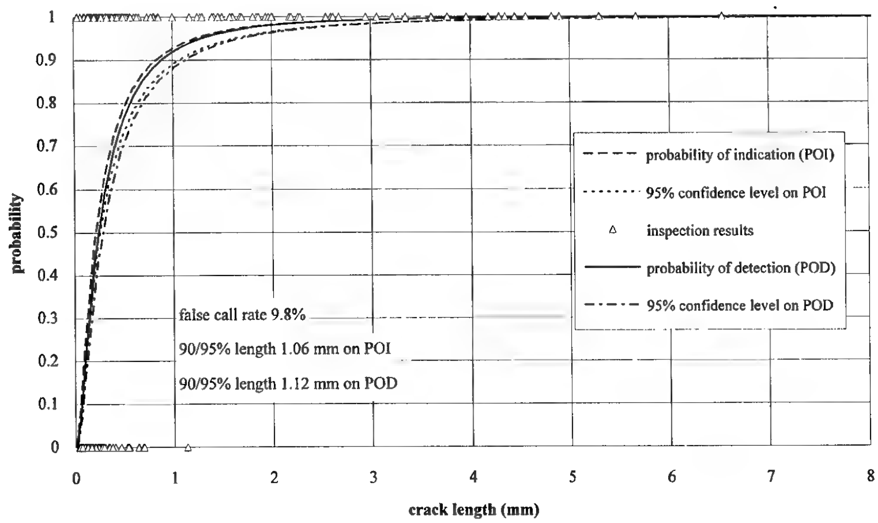


Figure 17. Dependence of POI and POD on crack length, ECI organization III

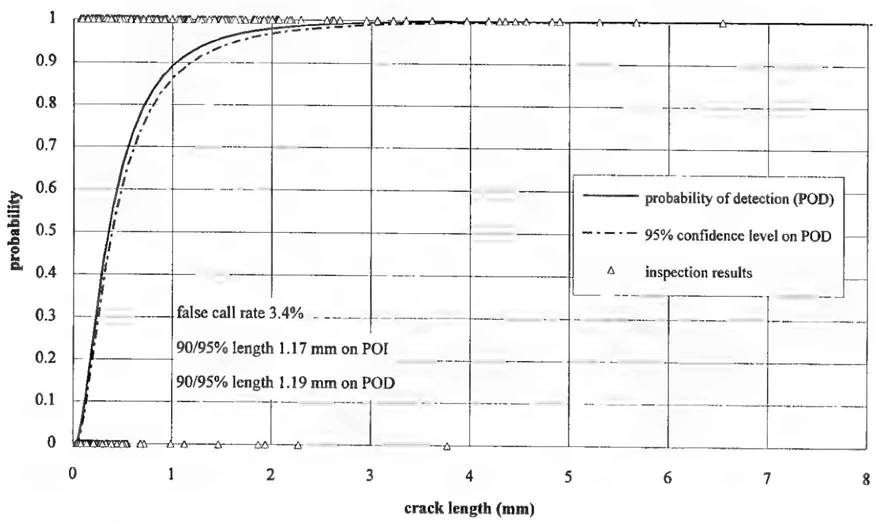


Figure 18. Dependence of POD on crack length, ECI organization IV

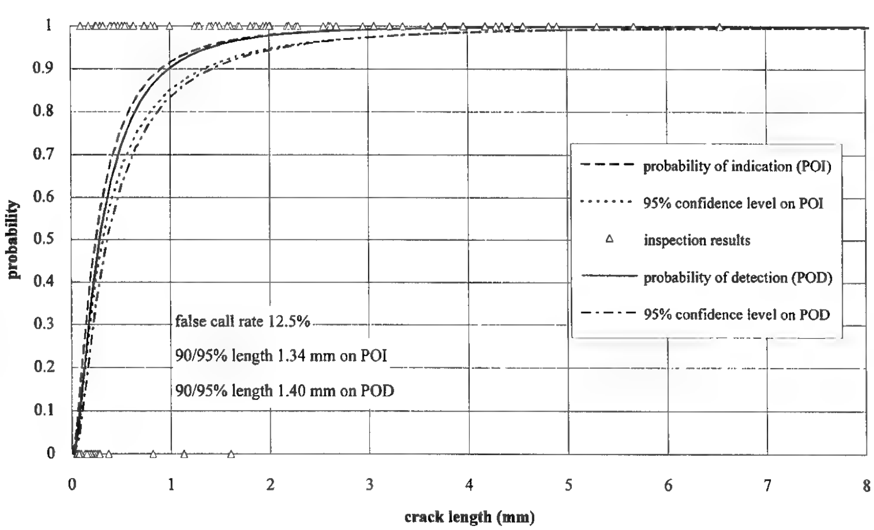


Figure 19. Dependence of POI and POD on crack length, ECI organization V

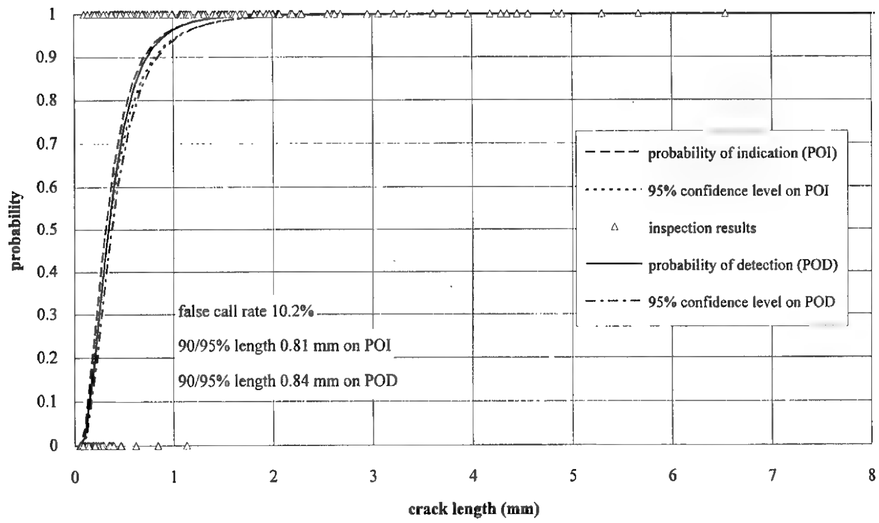


Figure 20. Dependence of POI and POD on crack length, ECI organization VI

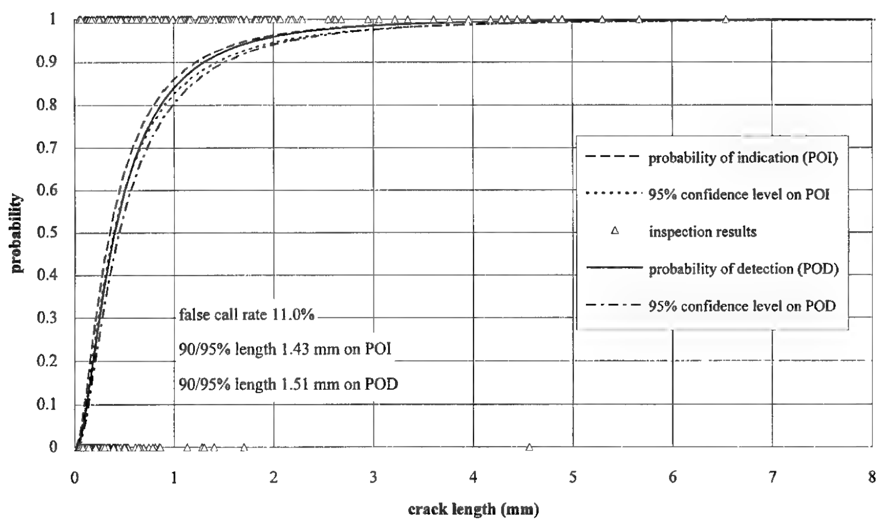


Figure 21. Dependence of POI and POD on crack length, ECI - A organization IV

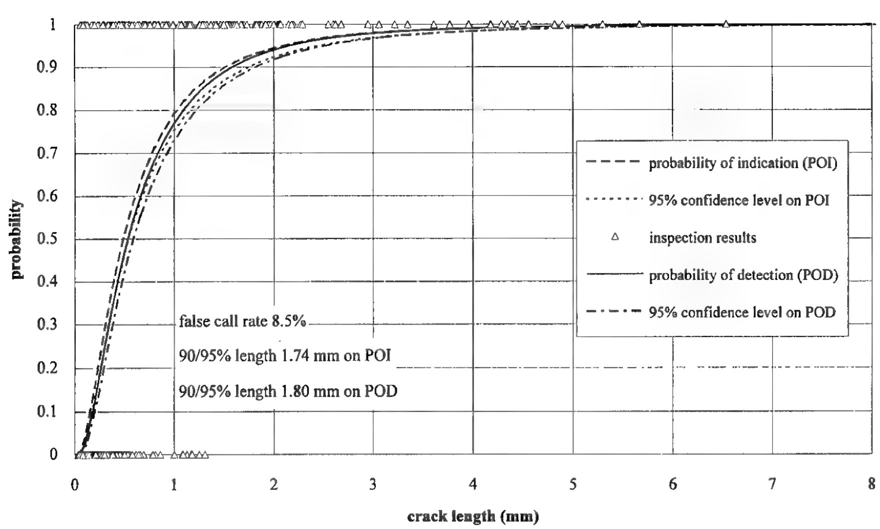


Figure 22. Dependence of POI and POD on crack length, ECI - AP organization IV

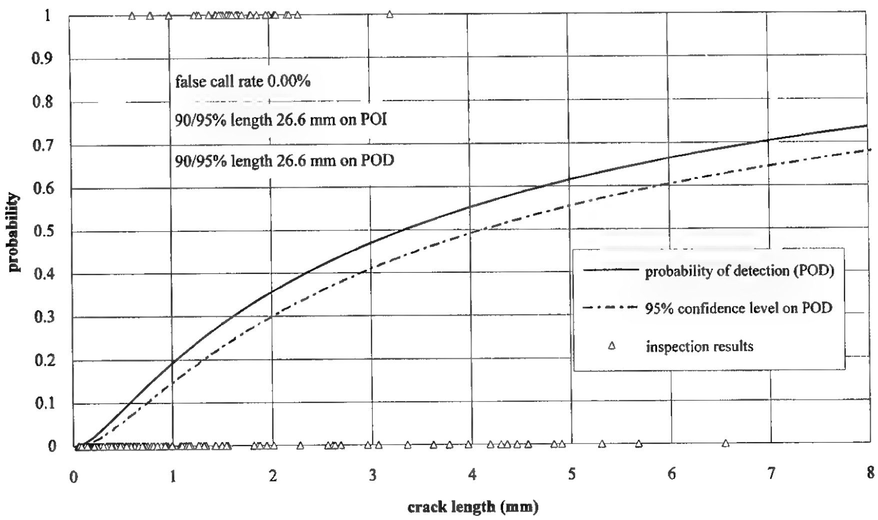


Figure 23. Dependence of POD on crack length, OMI organization VI

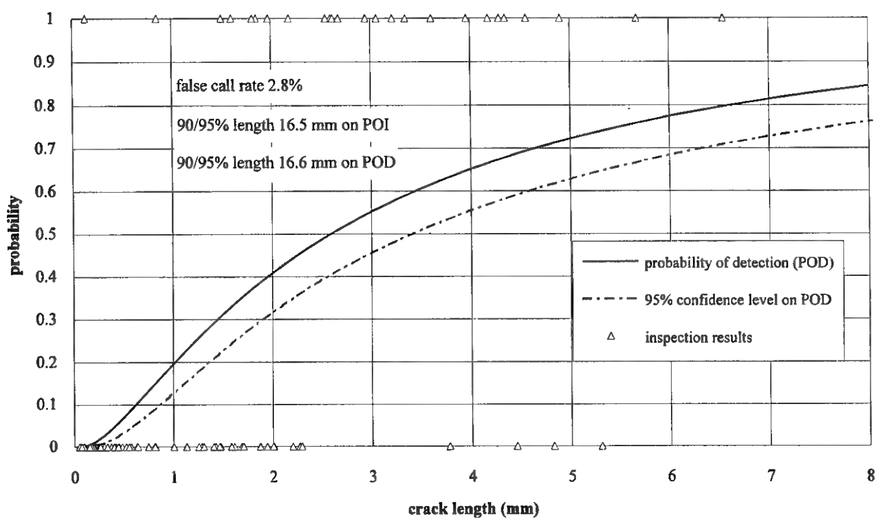


Figure 24. Dependence of POD on crack length, XRI organization IV

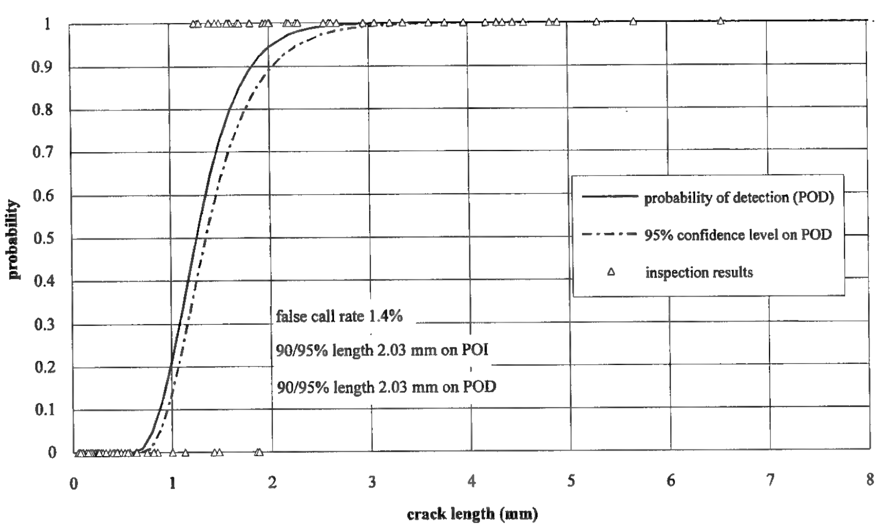


Figure 25. Dependence of POD on crack length, ULI organization IV

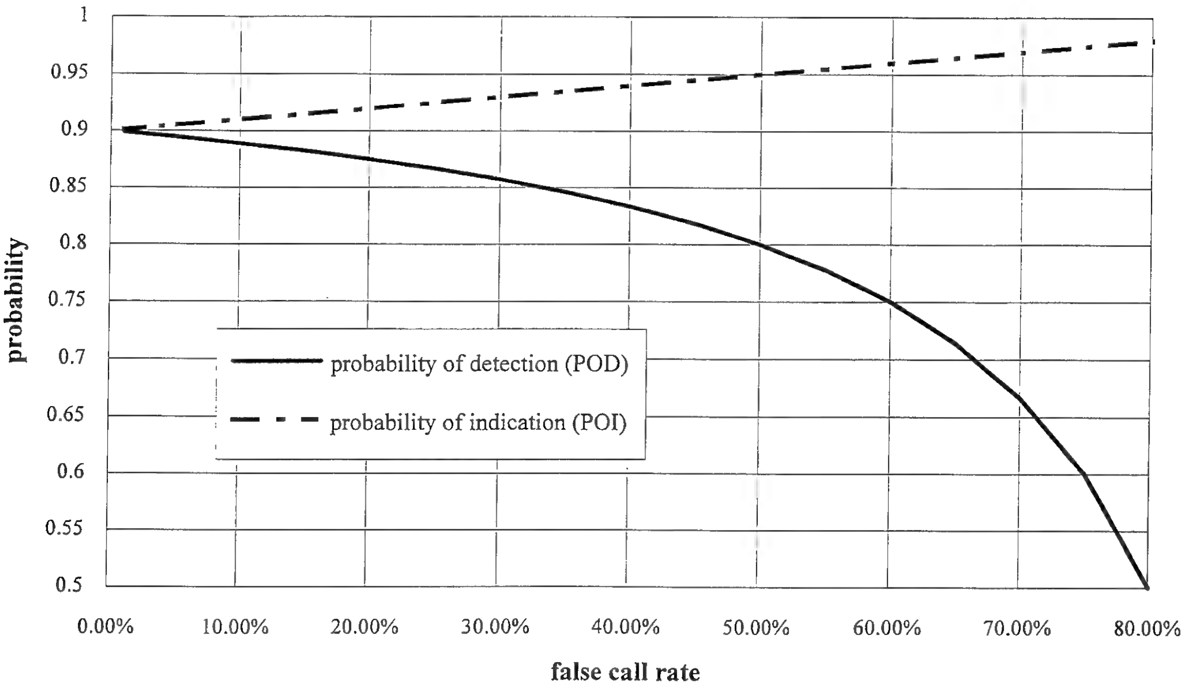


Figure 26. The effect of false call rate on probability of detection (POD) and probability of indication (POI)

Appendix A

Inspection Report Forms

LPI Inspection Report Form

Date: *Dec 1990* **Operator:** *Laboratory I*

Part description: *AGARD disks and spacers*

LPI system model number, name:

Standard procedure:
MIL STD 6866: type I, method B, sensitivity level 4

Inspection procedure - describe following:
a. precleaning

b. penetrant information
- 6850 01 121 0945 P/N FP 97A-M
- 60 min dwell time
c. penetrant removal

d.drying temperature and time

e. developer information and time
- 6850 01 121 0952 P/N D 76E
- 45 min
f. inspection method
- inspection under black light

g. post-cleaning

Defect evaluation: describe technique for inspection and defect analysis
- part examined under black light for crack indications, bore and surface of bolt holes

LPI Inspection Report Form

Date: *Jan 1992* **Operator:** *Laboratory III*

Part description: *AGARD disks and spacers*

LPI system model number, name:

Standard procedure:
MIL STD 6866: type I, method D

Inspection procedure - describe following:
a. precleaning
- solvent
b. penetrant information
- Magnaflux ZL27-A
- 30 min dwell time
c. penetrant removal
- rinse in water with 15% hydrophilic emulsifier (Magnaflux ZR10B)
d.drying temperature and time
- 70C recirculating oven
e. developer information and time
- immersion ZP-14Q
f. inspection method
- inspection under black light
- measurement using vernier calipers
g. post-cleaning
- blown clean

Defect evaluation: describe technique for inspection and defect analysis
- part examined under black light for crack indications, bore and surface of bolt holes
- indications measured using vernier calipers

LPI Inspection Report Form

Date: *Mar 1991* **Operator:** *Laboratory II*

Part description: *AGARD disks and spacers*

LPI system model number, name:

Standard procedure:
MIL STD 6866: type I, method D, sensitivity level 4

Inspection procedure - describe following:
a. precleaning
- acetone, then water rinse
b. penetrant information
- Magnaflux ZL37
- 30 min dwell time
c. penetrant removal
- hydrophilic emulsifier (Magnaflux ZR10B) for 60 seconds
d.drying temperature and time

e. developer information and time
- ZPQE
- 7 min
f. inspection method
- inspection under black light

g. post-cleaning

Defect evaluation: describe technique for inspection and defect analysis
- part examined under black light for crack indications, bore and surface of bolt holes

LPI Inspection Report Form

Date: *Oct 1990* **Operator:** *Laboratory IV*

Part description: *AGARD disks and spacers*

LPI system model number, name:
- Quality NDE Systems Ltd.
Standard procedure:
MIL STD 6866: type I, method D, sensitivity level 3

Inspection procedure - describe following:
a. precleaning
- acetone, then water rinse
b. penetrant information
- Magnaflux ZL30
- 20 min dwell time
c. penetrant removal
- water rinse, followed by hydrophilic emulsifier (Magnaflux ZR10B) for 60 seconds
d.drying temperature and time
- 60C for <30 minutes, until part is dry
e. developer information and time
- dry powder ZPQ
- 10 min dwell time
f. inspection method
- inspection under black light
- measurement using vernier calipers
g. post-cleaning
- blown clean
Defect evaluation: describe technique for inspection and defect analysis
- part examined under black light for crack indications, bore and surface of bolt holes
- indications measured using vernier calipers

MPI Inspection Report Form

Date: *Feb 1991* **Operator:** *Laboratory I*

Part Description: *AGARD disks and spacers*

MPI system model number, name:

Standard procedure:
MIL STD 1949A

Inspection procedure - describe following:
a. precleaning

b. magnetic suspension information

c. magnetic current

d. demagnetization

e. post-cleaning

Sketch inspection geometry:

MPI Inspection Report Form

Date: *Mar 1991* **Operator:** *Laboratory II*

Part Description: *AGARD disks and spacers*

MPI system model number, name:
- Magnaflux H720

Standard procedure:
MIL STD 1949A

Inspection procedure - describe following:
a. precleaning

b. magnetic suspension information

c. magnetic current

d. demagnetization

e. post-cleaning

Sketch inspection geometry:

MPI Inspection Report Form

Date: *Jan 1992* **Operator:** *Laboratory III*

Part Description: *AGARD disks and spacers*

MPI system model number, name:
- C.G.M. Censa FUS 500

Standard procedure:
MIL STD 1949A

Inspection procedure - describe following:
a. precleaning

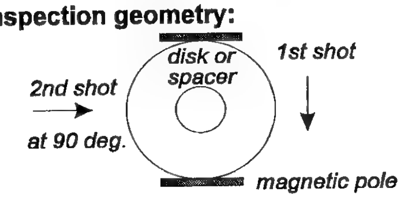
b. magnetic suspension information
- Magnaflux 14A dispersed in liquid RX/RG Carrier II

c. magnetic current
- 20 kA

d. demagnetization

e. post-cleaning

Sketch inspection geometry:



ECI Inspection Report Form

Date: *Jan 1991* **Operator:** *Laboratory I*

Part Description: *AGARD disks and spacers*

Material:
- AM355 martensitic stainless steel

Surface finish: *precipitation hardened*

Test Instrument:
- Magnaflux ED-520, serial number 6635 167 9826

Instrument settings
frequency: **scan speed:**
gain: **phase:**
filtering:

Probe geometry, type:
- Magnaflux bolt hole probe (1/4"-5/16") serial number 6635 00 018 5836
- modified for hole diameter 0.193"
Describe,sketch scan plan:

Describe technique for analysis of signal:

ECI Inspection Report Form

Date: *Jan 1992* **Operator:** *Laboratory III*

Part Description: *AGARD disks and spacers*

Material:
- AM355 martensitic stainless steel

Surface finish: *precipitation hardened*

Test Instrument:
- ELOTEST B1.3

Instrument settings
frequency: *500 kHz* **scan speed:** *3000 rpm*
gain: *46 dB* **phase:** *313 degrees*
filtering: *highpass 300 Hz*

Probe geometry, type:
- ELOTEST 4.4 mm diameter rotating differential probe

Describe,sketch scan plan:
- probe hand held, inserted into bolt hole

Describe technique for analysis of signal:

ECI Inspection Report Form

Date: *Oct 1990* **Operator:** *Laboratory IV*

Part Description: *AGARD disks and spacers*

Material:
- AM355 martensitic stainless steel

Surface finish: *precipitation hardened*

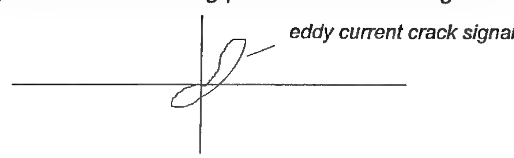
Test Instrument:
- ELOTEST B1.3

Instrument settings
frequency: *660 kHz* **scan speed:** *3000 rpm*
gain: *35 dB* **phase:** *191 degrees*
filtering: *bandpass centred at 500 Hz*

Probe geometry, type:
- ELOTEST 4.7 mm diameter rotating differential probe

Describe,sketch scan plan:
- probe hand held, inserted into bolt hole

Describe technique for analysis of signal:
- crack signal characterised by large amplitude signal at about 45 deg phase from liftoff signal



ECI Inspection Report Form

Date: *Sept 1992* **Operator:** *Laboratory V*

Part Description: *AGARD disks and spacers*

Material:
- AM355 martensitic stainless steel

Surface finish: *precipitation hardened*

Test Instrument:
- Rohmann Rototest

Instrument settings
frequency: *500 kHz* **scan speed:**
gain: *31dB* **phase:**
filtering:

Probe geometry, type:
- Rohmann rotating differential probe
- 4.8 mm diameter
- rotor 91.2.049

Describe,sketch scan plan:

Describe technique for analysis of signal:

ECI Inspection Report Form

Date: **Operator:** *Laboratory VI*

Part Description: *AGARD disks and spacers*

Material:
- AM355 martensitic stainless steel

Surface finish: *precipitation hardened*

Test Instrument:
- Rohmann Rototest

Instrument settings
frequency: *500 kHz* **scan speed:**
gain: *20dB* **phase:**
filtering:

Probe geometry, type:
- Rohmann rotating differential probe

Describe,sketch scan plan:

Describe technique for analysis of signal:

ECI Inspection Report Form

Date: *Oct 1990* **Operator:** *Laboratory IV*

Part Description: *AGARD disks and spacers*

Material:
- AM355 martensitic stainless steel

Surface finish: *precipitation hardened*

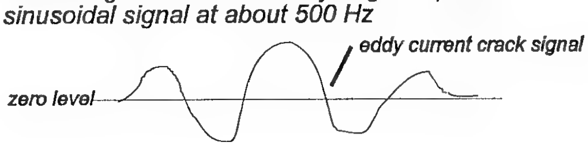
Test Instrument:
- ARIES automated eddy current system, using ELOTEST B1.3

Instrument settings
frequency: *660 kHz* **scan speed:** *3000 rpm*
gain: *26 dB* **phase:** *191 degrees*
filtering: *bandpass centred at 500 Hz*

Probe geometry, type:
- ELOTEST 4.7 mm diameter rotating differential probe

Describe,sketch scan plan:
- probe positioned automatically
- tested at six vertical positions, centred vertically in bolt hole, 1 mm apart
- records taken while probe stationary

Describe technique for analysis of signal:
- crack signal charaterised by large amplitude sinusoidal signal at about 500 Hz



Appendix B

Inspection Data

Abbreviations in Appendix B

Technique:

LPI	liquid penetrant inspection
MPI	magnetic particle inspection
ECI-M	eddy current inspection-manual
ECI-A	eddy current inspection-automatic
ECI-AP	eddy current inspection-automatic with pattern recognition
OMI	optical microscope inspection
XRI	X-ray inspection
ULI	ultrasonic leaky wave inspection
DI	destructive inspection

Result:

C	indicates crack found in destructive inspection
H	crack found or "hit" in inspection
M	crack missed
F	false call

Position:

th	through crack
c	corner crack
m	middle crack

DISK A

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length mm	crack area mm^2	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV					
Bolt hole #																							
1										F		F	F										
2																							
3										F		F	F										
4			F							F	F	F	F										
5	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	3.61	4.86	th	1
6	M	M	H	M		M	H	M	M	H	H	H	H	M	H	M	M	M	C	0.42	0.48	c	1
7	M	H	H	M		M	H	H	M	H	M	H	H	H	H	M	M	H	C	2.27	4.09	m	1
8	M	M	H	M		M	H	H	M	H	H	M	H	H	H	H	M	M	C	0.82	0.64	c	1
9	M	H	H	M		M	H	H	M	H	H	H	H	M	M	M	M	M	C	0.81	1.14	c	2
10	H	H	H	H		H	H	H	H	H	M	H	H	H	H	M	M	H	C	3.77	4.83	th	2
11			F					F			F		F										
12	M	M	H	M		M	H	H	M	H	H	H	H	M	H	M	H	M	C	0.85	1.07	c	1
13	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	4.90	6.27	th	1
14	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	M	H	C	4.45	5.70	th	2
15	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	4.18	5.64	th	2
16	H	H	H	M		H	H	H	H	H	H	H	H	H	H	M	H	H	C	2.60	4.68	th	2
17	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	4.56	6.16	th	2
18	M	H	H	M		M	H	H	M	H	H	H	H	H	H	M	H	M	C	1.85	3.33	th	1
19	M	H	H	M		H	H	H	H	H	H	H	H	H	H	M	H	H	C	2.55	2.55	c	1
20	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	3.96	6.34	th	1
21	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	5.67	7.65	th	3
22	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	2.95	4.86	c	2
23	M	H	H	M		M	H	H	M	H	H	H	H	H	H	H	M	H	C	2.29	4.12	th	2
24	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	M	H	C	4.82	6.75	th	3
25	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	4.35	5.87	th	2
26	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	6.54	8.83	th	2
27	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	4.29	5.79	th	2
28	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	1.81	2.41	th	1
29	M	H	H	H		M	H	H	M	H	H	H	H	M	H	M	H	H	C	4.56	1.70	th	3
30	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	M	H	C	5.30	7.16	th	2
31	M	H	M	M		H	H	H	M	H	M	H	H	H	H	M	M	H	C	1.94	2.26	c	1
32	M	M	M	M		M	M	H	M	M	H	M	M	M	H	M	H	M	C	0.13	0.02	c	1
33	M	H	H	M		M	H	H	M	H	H	H	H	H	H	M	M	M	C	1.42	2.34	th	1
34	M	H	H	M		M	H	H	M	H	M	H	H	H	H	H	M	M	C	1.47	2.40	th	2
35		F									F						F						
36	M	M	M	M		M	H	M	M	H	H	H	H	M	H	M	M	M	C	0.75	0.66	c	1
37	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	3.06	3.76	c	2
38	M	H	H	M		M	H	H	M	H	M	H	H	H	H	M	M	M	C	1.87	1.80	th	1
39												F	F										
40							F																
total hit	17	27	29	17		19	31	30	18	31	27	30	31	26	31	3	18	22	32				
total missed	15	5	3	15		13	1	2	14	1	5	2	1	6	1	29	14	10					
false calls	0	1	2	0		0	1	1	0	3	3	4	5	0	0	0	1	0					

DISK B

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length mm	crack area mm^2	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV					
Bolt hole #																							
1																							
2								F															
3																							
4																							
5																							
6								F															
7																							
8																							
9	M	H	M	M		H	H	H	H	H	H	H	H	H	H	H	M	H	C	1.40	1.80	c	2
10													F										
11												F											
12	H	H	H	H		H	H	H	H	H	H	M	H	H	H	H	H	H	C	1.60	2.40	th	1
13												F											
14	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M	M	M	C	0.26	0.07	c	1
15								F															
16			F					F															
17								F															
18								F															
19	M	M	M	M		M	M	M	M	M	M	M	M	M	H	M	M	M	C	0.24	0.04	c	1
20								F															
21																	F						
22							F											F					
23	M	M	M	M		M	H	H	M	H	H	H	H	M	H	H	M	H	C	1.40	1.50	c	2
24								F															
25	M	M	M	M		M	M	H	M	M	M	M	H	M	H	M	M	M	C	0.22	0.06	m	1
26	M	M	M	M		M	M	M	M	H	M	H	H	H	M	M	M	M	C	0.45	0 18	c	2
27	M	M	M	M		M	M	M	M	M	M	M	M	M	H	M	M	M	C	0.20	0.03	c	1
28	M	M	H	M		M	M	H	M	H	H	H	H	H	H	M	M	M	C	0.10	0.01	c	1
29								F															
30	M	M	M	M		M	M	M	M	M	H	H	H	M	M	M	M	M	C	0.25	0.06	c	2
31	M	M	M	M		M	M	M	M	H	H	H	H	H	H	M	M	M	C	0.57	0.28	c	2
32	M	M	H	M		M	M	H	M	H	H	H	H	H	H	M	M	M	C	0.18	0 04	c	3
33	M	M	H	M		M	M	H	M	H	H	H	H	H	H	M	M	M	C	0.48	0.30	c	3
34	M	H	H	M		M	H	H	M	H	H	H	H	H	H	H	H	H	C	1.50	1.80	c	1
35																							
36																							
37								F															
38																							
39																							
40	M	M	M	M		M	M	H	M	M	M	H	H	M	H	M	M	M	C	0.25	0.10	c	1
total hit	1	3	5	1		2	4	9	2	9	9	10	12	8	12	4	2	4	15				
total missed	14	12	10	14		13	11	6	13	6	6	5	3	7	3	11	13	11					
false calls	0	0	1	0		0	1	10	0	0	0	2	1	0	0	0	1	1					

DISK C

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		hole
Bolt hole #																							
1							F	F															
2										F													
3																							
4	M	M	H	M		M	M	H	M	M	M	H	H	H	H	M	M	M	C	0.30	0.30	c	1
5								F															
6	M	M	M	M		M	M	M	M	H	H	H	H	H	H	H	M	M	C	0.63	0.36	c	1
7																							
8	H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	M	H	C	1.68	1.54	c	1
9	M	M	M	M		M	M	M	M	M	M	M	M	M	H	M	M	M	C	0.19	0.01	c	1
10								F															
11																							
12																							
13																							
14																							
15								F															
16													F										
17							F																
18								F															
19																							
20	M	M	M	H		M	M	M	M	M	H	H	H	H	H	M	M	M	C	0.64	0.51	c	1
21	M	M	M	H		M	H	H	M	H	H	H	H	H	H	H	M	H	C	1.46	1.56	c	1
22	M	M	M	M		M	H	M	M	H	H	H	H	H	M	H	M	M	C	0.81	0.92	c	2
23	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	2.62	3.54	th	1
24	H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	M	H	C	1.61	2.91	th	1
25	H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	H	H	C	1.97	2.68	c	1
26	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	2.68	4.90	th	1
27	H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	H	H	C	2.18	2.51	th	1
28	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	M	H	C	2.01	2.59	c	2
29	H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	H	H	C	3.22	5.10	th	2
30	H	H	H	H		H	H	H	H	H	H	H	H	H	H	M	H	H	C	3.35	5.75	th	2
31	M	M	M	M		M	M	M	M	H	M	M	M	H	H	M	M	M	C	0.37	0.19	m	2
32										F													
33	M	M	M	M		M	H	M	M	M	M	H	H	M	M	M	M	M	C	0.52	0.39	m	
34																							
35	M	M	H	M		M	M	H	M	M	M	M	M	M	M	M	M	M	C	1.13	0.17	c	
36								F															
37	M	M	M	M		M	M	H	M	M	M	H	H	M	M	M	M	M	C	0.40	0.94	c	
38																							
39															F								
40							F																
total hit	9	9	11	11		9	12	13	9	13	13	16	16	15	15	8	6	10	19				
total missed	10	10	8	8		10	7	6	10	6	6	3	3	4	4	11	13	9					
false calls	0	0	0	0		0	3	6	0	2	0	0	1	0	1	0	0	0					

DISK E

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		hole
Bolt hole #																							
1	M	M	H	M		M	H	H	M	H	H	H	H	H	M	H		M	C	1	1	t	3
2	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M		M	C	0.28	0.06	b	2
3	M	M	M	M		M	M	M	M	M	M	H	H	M	M	M		M	C	0.30	0.14	t	
4																							
5																							
6	M	M	M	M		M	M	H	M	M	M	M	M	M	M	M		M	C	0.06	0.01	t	1
7																							
8							F																
9																							
10			F					F															
11								F															
12										F		F											
13			F							F													
14							F																
15	M	M	M	M		M	M	M	M	M	M	H	H	M	M	M		M	C	0.26	0.09	m	
16	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M		M	C	0.09	0.02	m	8
17	M	M	M	M		M	H	M	M	M	M	H	H	M	M	M		M	C	0.33	0.16	b	2
18	M	M	M	M		M	M	M	M	H	H	H	H	M	M	M		M	C	0.44	0.14	t	6
19	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M		M	C	0.17	0.05	m	3
20	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M		M	C	0.06	0.00	m	
21												F	F										
22																							
23	M	M	M	M		M	H	M	M	H	M	H	H	H	H	M		M	C	0.55	0.24	b	1
24				F																			
•25	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M		M	C	0.15	0.02	t	1
26												F	F										
27	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M		M	C	0.05	0.01	t	1
28																							
29																							
30																							
31	M	M	M	M		M	M	M	M	M	M	M	M	M	M	M		M	C	0.07	0.01	m	2
32															F								
33	M	M	H	M		M	H	H	M	H	H	H	H	M	H	H		H	C	1.28	1.29	t	2
34	H	M	M	H		H	H	H	H	H	H	H	H	H	M	H		H	C	2.00	3.30	th	
35	M	M	H	H		M	H	H	M	H	H	H	H	M	H	H		H	C	1.30	1.29	t	2
36	H	M	H	M		H	H	H	H	H	H	H	H	M	H	H		H	C	1.70	2.00	t	2
37	H	H	H	H		H	H	H	H	H	H	H	H	H	H	H		H	C	2.20	3.90	th	
38	M	M	M	H		H	H	H	H	H	H	H	H	H	M	H		H	C	1.25	1.70	t	3
39	H	M	H	H		H	H	M	H	H	H	H	H	H	H	H		H	C	1.58	2.20	t	
40	M	M	H	M		M	H	H	M	H	H	H	H	H	H	H		H	C	1.30	1.60	th	
total hit	4	1	7	5		5	11	9	5	11	10	14	14	7	7	9		8	22				
total missed	18	21	15	17		17	11	13	17	11	12	8	8	15	15	13		14					
false calls	0	0	2	1		0	2	2	0	2	0	3	2	0	1	0		0					

Spacer H side 1

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		
Bolt hole #																							
1																							
2															F								
3																		F					
4														F				F					
5																							
6																							
7																							
8																		F					
9																		F					
10																							
11																		F					
12																		F					
13																							
14														F									
15		M	M				M	M		H	M			M	M			M	C	0.22	0.09	c	1
16																							
17		M	M				M	M		H	H			M	M			H	C	0.86	0.30	c	1
18		M	M				H	M		H	H			M	M			H	C	0.66	0.47	c	1
19																		F					
20																		F					
21																		F					
22																		F					
23														F	F								
24														F	F								
25																							
26														F									
27										F	F												
28																							
29		M	M				M	M		H	M			M	M			M	C	0.16	0.02	c	1
30																							
31		M	M				M	M		H	M			M	H			M	C	0.29	0.08	c	1
32																							
33																							
34																							
35																							
36																							
37		M	M				M	M		H	M			M	M			H	C	0.16	0.03	c	1
38																							
39																							
40																							
total hit		0	0				1	0		6	2			0	1			3	6				
total missed		6	6				5	6		0	4			6	5			3					
false calls		0	0				0	0		1	1			5	3			10					

Spacer H side 2

Technique	LPI					MPI			ECI-M					ECI-A	ECI AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		
Bolt hole #																							
1	M	M		M	M	M	M		M		H		H	H	M	M		M	C	0.41	0.14	c	4
2	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.21	0.06	c	
3	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.20	0.05	c	3
4	M	M		M	M	M	H		M		M		M	M	M	M		M	C	0.18	0.04	c	3
5	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.22	0.08	c	2
6	M	M		M	M	M	H		M		H		H	H	M	M		H	C	1.08	0.92	c	1
7	M	M		M	M	M	H		M		H		H	H	H	M		H	C	1.07	1.12	c	1
8	M	M		H	M	M	M		M		H		H	H	M	M		M	C	0.47	0.48	c	1
9	M	M		M	M	M	M		M		H		H	H	M	M		M	C	0.45	0.24	c	1
10																							
11	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.21	0.06	c	1
12	H	H		H	H	H	H		H		H		H	H	H	M		H	C	1.18	1.46	th	1
13	M	M		M	M	M	M		M		H		H	H	H	M		M	C	0.47	0.28	c	1
14	M	M		M	M	M	M		M		H		H	H	H	M		M	C	0.60	0.39	c	2
15	M	M		M	M	M	M		M		H		M	H	H	M		M	C	0.84	0.71	c	4
16	M	M		M	M	M	M		M		M		H	M	M	M		M	C	0.14	0.03	c	3
17	M	M		M	M	M	M		M		H		M	H	M	M		M	C	0.29	0.10	c	3
18	H	H		H	H	H	H		H		H		H	H	H	H		H	C	1.47	2.23	c	3
19	M	M		M	M	M	H		M		H		H	H	H	M		M	C	1.13	1.20	c	2
20	M	M		M	M	M	M		M		H		H	H	H	M		M	C	0.50	0.55	c	1
21	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.12	0.02	c	1
22	M	M		M	M	M	H		M		H		H	H	H	M		M	C	0.90	0.43	c	2
23	M	M		M	M	M	H		M		M		M	M	M	M		M	C	0.35	0.10	c	1
24	H	H		H	H	H	H		H		H		H	H	H	H		H	C	1.54	2.74	th	1
25	H	H		H	H	H	M		H		H		H	H	H	H		H	C	1.52	2.74	th	1
26	M	M		M	M	M	M		M		H		M	H	M	M		M	C	0.34	0.11	c	2
27	M	M		M	M	M	M		M		H		M	M	H	M		M	C	0.35	0.24	m	2
28																							
29	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.24	0.06	c	1
30																		F					
31	M	M		M	M	M	M		M		H		M	H	H	M		M	C	0.35	0.12	c	2
32	M	M		M	M	M	M		M		H		M	H	M	M		M	C	0.35	0.11	c	1
33	M	M		M	M	M	M		M		H		H	H	H	M		M	C	0.50	0.22	c	1
34	M	M		M	M	M	H		M		H		H	H	H	M		H	C	1.11	1.26	c	1
35																							
36	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.18	0.03	c	1
37	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.09	0.01	m	1
38	M	M		M	M	M	M		M		M		H	H	H	M		M	C	0.72	0.48	c	1
39	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.35	0.10	c	1
40	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.26	0.06	c	1
total hit	4	4		5	4	4	10		4		22		18	22	16	3		7	36				
total missed	32	32		31	32	32	26		32		14		18	14	20	33		29					
false calls	0	0		0	0	0	0		0		0		0	0	0	0		1					

Spacer I side 1

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		
Bolt hole #																							
1		M	M				M	M		H	M			M	M			M	C	0.536	0.336	c	1
2															F								
3										F					F								
4																							
5														F				F					
6		M	M				M	M		M	M			H	H			M	C	0.33	0.15	m	1
7		M	M				M	M		H	M			H	H			H	C	0.11	0.01	c	5
8										F													
9		M	M				M	M		H	M			M	M			M	C	0.14	0.03	m	1
10										F								F					
11		M	M				M	M		M	M			H	M			M	C	0.12	0.02	c	2
12		M	M				M	M		M	M			M	M			M	C	0.12	0.03	c	4
13							F			F				F				F					
14										F								F					
15		M	M				H	M		H	M			M	M			H	C	0.07	0.01	c	1
16		M	M				M	M		H	M			M	M			H	C	0.03	0.00	c	1
17		M	M				M	M		M	M			M	M			H	C	0.12	0.02	c	1
18		M	M				H	M		M	M			M	M			M	C	0.12	0.02	m	1
19														F				F					
20		M	M				M	M		M	M			M	M			H	C	0.16	0.04	c	1
21																		F					
22		M	M				M	M		M	M			M	M			H	C	0.24	0.06	c	2
23														F				F					
24																		F					
25																		F					
26															F			F					
27		M	M				M	M		M	M			M	H			H	C	0.17	0.05	c	2
28														F				F					
29		M	M				M	M		M	M			M	M			H	C	0.13	0.03	c	3
30		M	M				M	M		H	M			M	M			H	C	0.43	0.19	c	2
31														F				F					
32		M	M				M	M		M	M			H	M			M	C	0.20	0.06	m	3
33															F								
34										F													
35		M	M				H	M		H	M			M	M			M	C	0.30	0.14	c	4
36		M	M				M	M		H	H			M	M			M	C	0.20	0.04	c	3
37		M	M				M	M		M	M			M	M			H	C	0.14	0.02	c	2
38		M	M				M	M		M	M			M	M			M	C	0.23	0.08	m	1
39																							
40		M	M				M	M		M	M			H	H			M	C	0.06	0.00	c	1
total hit		0	0				3	0		8	1			5	4			10	21				
total missed		21	21				18	21		13	20			16	17			11					
false calls		0	0				1	0		6	0			6	4			12					

Spacer I side 2

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm			
Bolt hole #																							
1																							
2	H	H		H		H	H		H		H			H	H			H	C	1.97	3.55	th	5
3	H	H		H		M	H		H		H			H	H			H	C	2.29	4.12	th	3
4	M	M		M		M	M		M		H			H	H			M	C	0.93	0.99	c	5
5	H	H		H		H	H		H		H			H	H			H	C	2.20	3.96	th	3
6	H	H		H		H	H		H		H			H	H			H	C	2.04	3.67	th	3
7	M	M		M		M	M		M		H			H	H			M	C	0.80	0.44	c	9
8	H	H		H		H	H		H		H			H	H			H	C	2.05	2.90	th	2
9	M	M		M		M	H		M		H			H	H			H	C	1.56	2.81	th	3
10	M	M		M		M	M		M		H			H	M			M	C	0.27	0.10	c	3
11	H	H		H		H	H		H		H			H	H			H	C	1.83	2.59	th	2
12	M	M		M		M	M		M		M			M	H			M	C	0.29	0.07	c	4
13	H	H		H		H	H		H		H			H	H			H	C	1.85	3.33	th	2
14	M	M		M		M	M		M		M			M	M			H	C	0.08	0.01	m	1
15																		F					
16																		F					
17	H	H		H		H	H		H		H			H	H			H	C	1.88	3.20	th	6
18																							
19	M	M		M		M	M		M		M			M	H			H	C	0.11	0.02	c	1
20																							
21	M	M		M		M	M		M		M			M	M			M	C	0.18	0.02	c	1
22	M	M		M		M	M		M		M			H	M			M	C	0.18	0.04	c	1
23	H	H		H		H	H		H		H			H	H			H	C	1.96	3.53	th	3
24	M	M		M		M	M		M		M			M	M			M	C	0.14	0.03	m	1
25																							
26																							
27																							
28														F									
29	H	H		H		H	H		H		H			H	H			H	C	1.95	3.51	th	3
30																							
31	M	H		M		M	H		H		H			H	H			H	C	1.40	1.98	c	4
32																							
33	M	M		M		M	M		M		M			M	M			M	C	0.20	0.04	c	2
34																							
35	H	H		H		H	H		H		H			H	H			H	C	1.92	3.46	th	2
36																							
37																							
38																							
39																							
40																							
total hit	11	12		11		10	13		12		16			17	17			15	23				
total missed	12	11		12		13	10		11		7			6	6			8					
false calls	0	0		0		0	0		0		0			1	0			2					

Spacer J side 1

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		
Bolt hole #																							
1		M	M				M	M		M	M			M	M			M	C	0.09	0.013	c	2
2		M	M				M	M		M	M			M	M			M	C	0.46	0.20	m	3
3		M	M				M	M		M	M			M	M			M	C	0.22	0.06	m	4
4		M	M				M	M		M	M			H	M			M	C	0.05	0.00	m	1
5																		F					
6		M	M				M	M		M	M			H	H			M	C	0.13	0.02	c	3
7		M	M				M	M		M	M			H	H			H	C	0.34	0.07	c	2
8		M	M				M	M		M	M			H	H			M	C	0.54	0.29	c	1
9		M	M				M	M		M	M			M	M			H	C	0.53	0.23	c	3
10		M	M				M	M		M	M			M	M			M	C	0.13	0.03	c	7
11		M	M				M	M		M	M			M	H			H	C	0.29	0.09	c	3
12		M	M				M	M		M	M			M	M			M	C	0.23	0.07	c	3
13		M	M				M	M		M	M			H	H			M	C	0.68	0.42	c	1
14														F									
15		M	M				M	M		H	M			M	M			H	C	0.51	0.21	c	1
16		M	M				M	M		M	M			M	M			M	C	0.04	0.00	c	11
17		M	M				M	M		M	M			M	M			M	C	0.27	0.10	c	1
18																		F					
19																							
20		M	M				M	M		M	M			M	M			M	C	0.10	0.02	m	2
21		M	M				M	M		M	M			M	M			M	C	0.05	0.04	c	1
22																							
23		M	M				M	M		M	M			M	M			M	C	0.20	0.02	c	2
24		M	M				M	M		M	M			H	M			H	C	0.14	0.02	c	3
25																							
26														F									
27		M	M				M	M		M	M			M	M			M	C	0.29	0.09	c	1
28		M	M				M	M		H	M			H	M			M	C	0.27	0.06	c	2
29														F				F					
30																							
31														F									
32																							
33		M	M				M	M		M	H			M	M			M	C	0.69	0.65	c	1
34											F												
35		M	M				M	M		H	H			M	M			M	C	0.61	0.34	c	1
36		M	M				M	M		M	M			M	M			M	C	0.11	0.02	c	1
37		M	M				M	M		H	M			M	M			M	C	0.29	0.07	c	3
38		M	M				M	M		M	M			M	M			M	C	0.12	0.03	c	2
39		M	M				M	M		M	M			H	M			M	C	0.37	0.09	c	4
40		M	M				M	M		M	M			H	M			M	C	0.15	0.02	m	5
total hit		0	0				0	0		4	2			9	5			5	28				
total missed		28	28				28	28		24	26			19	23			23					
false calls		0	0				0	0		0	1			4	0			3					

Spacer J side 2

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		
Bolt hole #																							
1	H	H		H		H	H		H		H		H	H	H	H		H	C	1.81	3.24	th	2
2	M	M		M		M	M		M		M		M	M	M	M		M	C	0.18	0.04	c	2
3	M	M		M		M	M		M		M		M	M	M	M		M	C	0.06	0.00	c	1
4	M	M		M		M	M		M		H		H	H	H	M		M	C	0.64	0.29	c	5
5	M	M		M		M	M		M		H		M	M	M	M		M	C	0.07	0.01	m	3
6	M	M		M		M	M		M		M		M	M	M	M		M	C	0.11	0.02	c	3
7	M	M		M		M	M		M		M		M	M	M	M		M	C	0.18	0.05	m	5
8	M	M		M		M	M		M		H		H	M	M	M		M	C	0.49	0.41	c	2
9	M	M		M		M	M		M		M		M	M	M	M		M	C	0.16	0.04	c	15
10	M	M		M		M	M		M		M		M	M	M	M		M	C	0.27	0.10	c	2
11	M	M		M		M	M		M		M		M	M	M	M		M	C	0.14	0 03	c	4
12	M	M		M		M	M		M		H		H	H	M	M		M	C	0.55	0.45	c	5
13	M	M		M		M	M		M		M		M	M	M	M		M	C	0.07	0.01	m	4
14	M	M		M		M	M		M		M		M	M	M	M		M	C	0.19	0.05	m	6
15									F														
16	M	M		M		M	M		M		M		M	M	M	M		M	C	0.13	0.02	c	2
17	M	M		M		M	M		M		M		M	M	M	M		M	C	0.09	0.01	m	6
18	M	M		M		M	M		M		M		M	H	M	M		M	C	0.23	0.09	c	2
19	M	M		M		M	M		M		M		H	H	M	M		M	C	0.37	0.21	m	4
20	M	M		M		M	M		M		M		M	M	M	M		M	C	0.14	0 03	m	8
21	M	M		M		M	M		M		H		H	H	M	M		M	C	0.47	0.39	m	3
22	M	M		M		M	M		M		H		M	H	M	M		M	C	0.62	0.34	c	4
23	M	M		M		M	M		M		M		M	M	M	M		M	C	0.15	0.03	c	5
24	M	M		M		M	M		M		H		M	M	M	M		M	C	0.15	0.03	c	7
25	M	M		M		M	M		M		M		M	M	M	M		M	C	0.15	0.04	c	2
26																							
27	M	M		M		M	M		M		M		M	M	M	M		M	C	0.10	0.01	m	8
28	H	H		H		H	H		H		H		H	H	H	H		H	C	1.82	2.57	th	2
29	M	M		M		M	M		M		H		H	H	M	M		M	C	0.58	0.28	c	2
30	M	M		M		M	M		M		M		M	H	M	M		M	C	0.47	0.14	c	9
31	H	H		H		H	H		H		H		H	H	H	H		H	C	2.05	3.69	th	1
32	M	M		M		M	M		M		H		H	H	H	M		M	C	1.33	1.66	c	2
33	M	M		M		M	M		M		M		M	M	M	M		M	C	0.10	0.02	m	4
34	M	M		M		M	M		M		M		M	M	M	M		M	C	0.21	0.07	m	9
35	H	H		H		H	H		H		H		H	H	H	H		H	C	1.88	3.29	th	1
36	M	H		M		M	H		H		H		H	H	H	M		H	C	1.25	1.58	th	1
37	H	H		H		H	H		H		H		H	H	H	H		H	C	2.06	3.40	th	1
38	M	H		M		M	H		M		H		H	H	H	M		M	C	1.08	0.93	c	1
39	M	H		M		M	H		M		H		H	H	H	M		M	C	1.00	1.24	c	1
40	M	M		M		M	M		M		H		M	H	M	M		M	C	0.46	0.18	c	1
total hit	5	8		5		5	8		6		18		15	18	10	5		6	38				
total missed	33	30		33		33	30		32		20		23	20	28	33		32					
false calls	0	0		0		0	0		1		0		0	0	0	0		0					

Spacer K side 1

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length mm	crack area mm^2	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV					
Bolt hole #																							
1															F								
2																							
3		M	M				M	M		M	M			M	M			M	C	0.08	0.01	c	1
4																							
5																							
6		M	M				M	M		M	M			M	M			M	C	0.12	0.02	m	1
7															F								
8		M	M				M	M		H	M			M	M			M	C	0.35	0.11	c	1
9																							
10																							
11		M	M				M	M		M	M			M	M			M	C	0.10	0.01	c	1
12																							
13		M	M				M	M		M	M			M	M			M	C	0.10	0.02	m	1
14		M	M				M	M		M	M			M	M			M	C	0.20	0.06	m	2
15																							
16																							
17		M	M				M	M		M	M			M	M			H	C	0.08	0.01	c	1
18		M	M				M	M		H	H			M	M			M	C	0.43	0.28	c	1
19		H	M				H	M		H	H			H	M			H	C	1.17	1.30	c	1
20																							
21																							
22		M	M				M	M		H	H			H	H			M	C	0.52	0.26	c	1
23														F									
24																							
25		M	M				M	M		M	M			M	M			M	C	0.20	0.04	c	1
26																							
27																							
28																							
29								F															
30																							
31																							
32																							
33																							
34																		F					
35																							
36		M	M				M	M		H	M			M	M			M	C	0.19	0.03	c	1
37																							
38		M	M				M	M		M	M			M	M			M	C	0.07	0.01	c	1
39																							
40		M	M				M	M		M	M			M	M			M	C	0.09	0.01	c	1
total hit		1	0				1	0		5	3			2	1			2	14				
total missed		13	14				13	14		9	11			12	13			12					
false calls		0	0				0	1		0	0			1	2			1					

Spacer K side 2

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length mm	crack area mm^2	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV					
Bolt hole #																							
1	M	M		M		M	M		M		H		H	H	M	M		M	C	1.18	1.306	c	1
2	H	H		H		H	H		H		H		H	H	H	H		H	C	2.07	2.92	c	1
3	M	M		M		M	M		M		H		H	M	M	M		M	C	0.66	0.25	c	1
4	H	H		H		H	H		H		H		H	H	H	H		H	C	1.61	2.90	th	3
5	M	M		M		M	M		M		H		H	H	H	M		M	C	0.24	0.05	c	7
6	M	M		M		M	M		M		H		M	M	H	M		M	C	0.38	0.11	c	1
7	M	H		M		M	H		M		H		H	H	H	M		M	C	1.55	1.76	c	2
8	H	H		H		H	H		H		H		H	H	M	M		H	C	1.09	1.54	c	1
9	M	M		M		M	M		M		H		M	H	M	M		M	C	0.46	0.19	c	1
10	M	M		M		M	M		M		H		H	H	M	M		M	C	0.78	0.53	c	1
11	M	H		M		M	H		M		H		H	H	H	M		M	C	0.70	0.44	c	1
12	M	M		M		M	M		M		H		H	H	H	M		M	C	0.66	0.71	c	1
13	M	M		M		M	M		M		H		M	H	M	M		M	C	0.36	0.12	c	1
14	M	M		M		M	H		M		H		H	H	H	M		H	C	1.28	1.29	c	1
15	M	H		H		M	H		M		H		H	H	H	M		H	C	1.43	2.02	th	1
16	M	M		M		M	M		M		H		H	H	H	M		M	C	0.69	0.45	c	2
17	M	M		M		M	M		M		H		H	H	H	M		M	C	0.93	0.79	c	1
18	M	M		M		M	M		M		H		H	H	H	M		M	C	0.41	0.15	c	1
19	M	M		H		M	M		M		H		H	H	H	M		M	C	0.95	0.40	m	3
20	M	M		M		M	M		M		H		M	H	M	M		M	C	0 34	0.09	c	3
21	M	M		M		M	M		M		H		H	H	H	M		M	C	0.93	0.87	c	2
22	M	M		M		M	H		M		H		H	H	H	M		M	C	0.88	0.69	c	2
23	M	M		M		M	H		M		H		H	H	H	M		M	C	0.80	0.55	c	4
24	H	H		H		H	H		H		H		H	H	H	H		H	C	1.97	3.24	th	3
25	M	M		M		M	M		M		H		H	M	M	M		M	C	0.19	0.06	m	5
26	M	M		M		M	H		M		H		H	H	H	M		M	C	0.92	0.74	c	1
27	M	M		M		M	M		M		H		H	H	H	M		M	C	0.84	0.64	c	2
28	M	M		M		M	M		M		M		M	M	M	M		M	C	0.14	0.02	c	1
29	M	M		M		M	M		M		H		H	H	M	M		M	C	0.53	0.22	c	1
30	M	M		M		M	M		M		H		M	M	H	M		M	C	0.09	0.04	c	1
31	M	M		M		M	H		M		M		H	H	H	M		M	C	0.99	0.93	c	1
32																				N/A	N/A	N/A	
33	M	H		M		M	H		M		H		H	H	H	M		H	C	1.31	1.85	c	3
34	H	H		H		H	H		H		H		H	H	H	M		H	C	1.49	2.11	th	1
35	M	M		M		M	H		M		H		H	H	M	M		M	C	0.44	0.20	c	2
36	M	M		M		M	H		M		H		H	H	H	M		H	C	1.26	1.61	c	2
37	H	H		H		H	H		H		H		H	H	H	M		H	C	1.54	2.17	th	1
38	M	M		M		M	H		M		H		H	H	H	M		M	C	1.14	1.13	c	1
39	H	H		H		H	H		H		H		H	H	H	H		H	C	1.73	1.97	th	3
40	M	M		M		M	M		M		H		M	M	M	M		M	C	0.35	0.08	c	5
total hit	7	11		9		7	19		7		38		32	33	28	4		11	39				
total missed	32	28		30		32	20		32		2		7	6	12	35		28					
false calls	0	0		0		0	0		0		0		0	0	0	0		0					

Spacer L side 1

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		hole
Bolt hole #																							
1		M	M				M	M		H	H			M	M			M	C	0.327	0.137	c	5
2		H	M				M	M		H	M			H	M			M	C	0.42	0.29	c	1
3		M	M				M	M		H	H			H	M			M	C	0.24	0.20	m	4
4		M	M				M	M		H	H			H	M			M	C	0.57	0.48	c	1
5		M	M				M	M		H	H			H	M			M	C	0.24	0.09	c	3
6		M	M				M	M		H	H			H	M			M	C	0.44	0.25	c	2
7		M	M				M	M		H	H			H	H			M	C	0.52	0.41	c	2
8		M	M				M	M		H	H			M	M			M	C	0.78	0.55	c	1
9		M	M				M	M		H	H			M	M			M	C	0.22	0.07	c	3
10		M	M				M	M		H	H			M	M			H	C	0.33	0.17	c	3
11		M	M				M	M		H	H			H	M			H	C	0.58	0.46	c	1
12		M	M				H	M		H	H			H	M			M	C	0.47	0.31	c	1
13		H	M				M	M		H	H			M	M			H	C	0.29	0.17	c	4
14		M	M				M	M		H	H			H	M			H	C	0.42	0.31	c	1
15		M	M				M	M		H	H			M	M			M	C	0.32	0.16	m	3
16		M	M				M	M		H	H			H	M			M	C	0.38	0.11	th	2
17		M	M				M	M		H	H			H	M			M	C	0.38	0.15	c	3
18		M	M				M	M		H	H			H	M			M	C	0.35	0.11	c	3
19		M	M				M	M		H	H			H	M			M	C	0.18	0.07	m	5
20		H	M				H	M		H	H			M	M			M	C	0.50	0.43	c	2
21		M	M				M	M		H	H			H	H			M	C	0.20	0.06	m	5
22		M	M				M	M		H	H			M	M			M	C	0.35	0.12	c	4
23		M	M				M	M		H	H			H	M			M	C	0.22	0.09	c	4
24														F	F								
25		M	M				M	M		H	H			M	M			H	C	0.27	0.07	c	4
26		M	M				M	M		H	M			M	M			M	C	0.16	0.03	c	6
27		M	M				M	M		H	M			H	M			M	C	0.18	0.04	c	4
28		M	M				M	M		M	M			H	M			M	C	0.07	0.01	m	1
29		M	M				M	M		H	H			H	M			H	C	0.26	0.14	c	4
30		M	M				M	M		H	H			M	M			M	C	0.49	0.25	c	2
31		M	M				M	M		H	H			H	M			M	C	0.20	0.04	c	2
32		M	M				M	M		H	M			H	M			M	C	0.18	0.05	c	3
33		M	M				M	M		H	M			M	H			H	C	0.28	0.07	c	4
34		M	M				M	M		H	M			M	M			M	C	0.20	0.07	c	4
35		M	M				M	M		H	M			M	M			M	C	0.40	0.21	c	2
36		M	M				M	M		H	M			M	M			M	C	0.27	0.12	c	3
37		M	M				M	M		H	M			M	M			M	C	0.16	0.05	m	4
38		M	M				M	M		H	M			H	M			H	C	0.44	0.43	c	1
39		M	M				M	M		H	M			H	H			H	C	0.50	0.16	c	3
40		M	M				M	M		H	M			M	M			M	C	0.16	0.04	c	1
total hit		3	0				2	0		38	26			22	4			9	39				
total missed		36	39				37	39		1	13			17	35			30					
false calls		0	0				0	0		0	0			1	1			0					

Spacer L side 2

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length	crack area	position	cracks at each
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV		mm	mm^2		hole
Bolt hole #																							
1	M	M		M		M	M		M		H			H	H	M		M	C	0.651	0.575	c	1
2	M	H		M		M	H		M		H			H	H	M		M	C	0.84	0.79	c	1
3	H	H		H		H	H		H		H			H	H	M		H	C	1.53	2.16	th	1
4	H	H		H		H	H		H		H			H	H	M		H	C	1.91	3.44	th	1
5	M	H		M		M	M		M		H			H	H	M		M	C	0.84	0.83	c	1
6	H	H		H		H	H		H		H			H	H	M		H	C	2.15	3.87	th	1
7	M	M		M		M	M		M		H			H	M	M		M	C	0.46	0.24	m	4
8	H	H		H		H	H		H		H			H	H	M		H	C	1.83	3.29	th	1
9	M	H		M		M	H		M		H			H	M	M		H	C	1.31	1.85	c	1
10	M	M		M		M	H		H		H			H	H	M		H	C	1.29	2.32	th	1
11	H	H		H		H	H		H		H			H	H	M		H	C	1.42	2.56	th	1
12	M	H		M		M	H		M		H			H	H	M		H	C	1.15	2.07	th	1
13	M	M		M		M	M		M		H			H	M	M		M	C	0.25	0.07	c	8
14	H	H		H		H	H		H		H			H	H	M		H	C	2.18	3.92	th	1
15	M	M		M		M	M		M		H			H	H	M		M	C	0.55	0.28	c	2
16	M	M		M		M	M		M		H			H	H	M		M	C	0.45	0.34	c	2
17	M	M		M		M	M		M		H			H	H	M		M	C	0.69	0.35	m	4
18	M	M		M		M	M		M		H			H	H	M		M	C	0.71	0.33	c	5
19	M	M		M		M	M		M		H			H	H	M		M	C	1.05	1.34	c	1
20	M	M		M		M	M		M		H			H	H	M		M	C	0.53	0.40	c	3
21	M	H		M		M	H		M		H			H	H	M		M	C	0.71	1.00	th	1
22	M	H		M		M	H		M		H			H	H	M		H	C	0.92	0.72	c	2
23	M	M		M		M	M		M		H			H	H	M		M	C	0.47	0.37	c	2
24	M	H		M		M	H		M		H			H	H	M		H	C	1.37	1.94	c	4
25	H	H		H		M	H		H		H			H	H	M		H	C	1.61	2.90	th	1
26	H	H		H		H	H		H		H			H	H	M		H	C	1.92	3.46	th	2
27	M	M		M		M	M		M		H			H	H	M		M	C	0.58	0.30	c	3
28	M	M		M		M	M		M		H			H	H	M		M	C	0.76	0.79	c	1
29	M	M		M		M	M		M		H			H	H	M		M	C	0.76	0.73	c	2
30	M	M		H		M	M		M		H			M	M	M		M	C	0.14	0.03	m	4
31	H	H		M		H	H		H		H			H	H	M		H	C	1.42	2.56	th	1
32	M	M		M		M	M		M		H			H	H	M		M	C	0.39	0.17	c	4
33	M	M		M		M	M		M		H			H	H	M		M	C	0.52	0.23	c	2
34	M	M		M		M	M		M		H			H	H	M		M	C	0.48	0.32	c	4
35	M	M		M		M	M		M		H			H	H	M		M	C	0.45	0.40	c	2
36	M	M		M		M	M		M		H			H	H	M		M	C	1.68	3.02	th	1
37	M	M		M		M	M		M		H			H	H	M		M	C	0.63	0.53	c	4
38	H	H		H		M	H		H		H			H	H	M		H	C	0.45	0.35	c	2
39	M	M		M		M	H		M		H			H	H	M		M	C	1.07	1.51	th	1
40	H	H		H		H	H		H		H			H	H	M		H	C	2.00	3.60	th	2
total hit	11	18		11		9	19		12		40			39	36	0		16	40				
total missed	29	22		29		31	21		28		0			1	4	40		24					
false calls	0	0		0		0	0		0		0			0	0	0		0					

Spacer M side 1

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length mm	crack area mm^2	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV					
Bolt hole #																							
1							F			F	F												
2	M	M		M			M	M		H	M			M	M			M	C	0.21	0.07	m	1
3										F													
4										F													
5	M	M		M			M	M		M	M			M	M			M	C	0.12	0.01	c	1
6														F									
7																							
8																							
9	M	M		M			H	M		H	M			M	M			M	C	0.21	0.06	c	1
10																							
11																							
12							F																
13																							
14										F													
15	M	M		M			M	M		H	H			M	M			M	C	0.64	0.21	c	1
16																							
17																							
18	M	M		M			M	M		H	M			M	M			M	C	0.28	0.06	c	1
19	M	M		M			M	M		H	M			M	M			M	C	0.22	0.04	c	1
20														F									
21	M	M		M			M	M		H	H			M	M			M	C	0.50	0.43	c	1
22																							
23																							
24																							
25																							
26														F	F								
27																							
28																							
29																							
30																							
31														F									
32	M	M		M			M	M		H	M			M	M			M	C	0.15	0.03	c	1
33	M	M		M			M	M		H	M			M	M			M	C	0.21	0.03	c	1
34																							
35	M	M		M			M	M		H	M			M	M			M	C	0.34	0.10	c	1
36																							
37	M	M		M			M	M		M	M			M	M			M	C	0.16	0.04	c	1
38		F					F																
39										F													
40														F									
total hit	0	0		0			1	0		9	2			0	0			0	11				
total missed	11	11		11			10	11		2	9			11	11			11					
false calls	0	1		0			3	0		5	1			5	1			0					

Spacer M side 2

Technique	LPI					MPI			ECI-M					ECI-A	ECI-AP	OMI	XRI	ULI	DI	crack length mm	crack area mm^2	position	cracks at each hole
Laboratory	I	II	III	IV	VI	I	II	III	I	III	IV	V	VI	IV	IV	VI	IV	IV					
Bolt hole #																							
1	M	M		M	M	M	M		M		H		H	H	M	M		M	C	0.42	0.145	c	1
2																							
3	H	M		M	M	M	M		M		M		M	M	M	M		M	C	0.15	0.02	c	1
4																							
5	M	M		M	M	M	H		M		M		H	M	M	M		M	C	0.33	0.15	m	2
6																							
7	M	M		M	M	M	M		M		H		M	H	M	M		M	C	0.39	0.13	c	1
8	M	M		M	M	M	M		M		M		H	M	M	M		M	C	0.39	0.13	c	1
9	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.15	0.03	c	1
10	M	M		M	M	M	M		M		M		H	M	M	M		M	C	0.21	0.04	c	1
11	H	H		H	M	H	H		H		H		H	H	H	H		H	C	1.67	2.79	th	1
12	M	H		M	M	H	M		M		M		M	M	M	M		M	C	0.09	0.01	c	1
13	H	M		H	M	M	H		H		H		H	H	H	H		H	C	1.50	2.40	th	3
14																		F					
15																		F					
16														F				F					
17														F				F					
18											F		F	F									
19																							
20	M	M		M	M	M	M		M		M		M	M	M	M		H	C	0.06	0.00	c	1
21	H	H		H	M	H	H		H		H		H	H	H	H		H	C	1.63	2.93	th	3
22	M	M		M	M	M	M		M		H		H	H	H	M		M	C	0.47	0.40	c	2
23	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.20	0.03	c	2
24																							
25	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.12	0.02	c	1
26	M	H		H	M	M	H		H		H		H	H	H	M		H	C	1.16	1.12	c	1
27																							
28																							
29															F								
30																							
31																							
32	M	M		M	M	M	M		M		M		M	M	M	M		H	C	0.08	0.01	m	1
33	M	M		M	M	M	M		M		H		H	H	M	M		M	C	0.38	0.13	c	1
34																							
35	M	M		M	M	M	M		M		M		H	M	M	M		M	C	0.30	0.07	c	1
36	M	M		M	M	M	M		M		M		H	M	M	M		M	C	0.21	0.05	c	2
37																							
38	M	M		M	M	M	M		M		M		M	M	M	M		M	C	0.14	0.19	c	1
39																							
40	F																						
total hit	4	4		4	0	3	5		4		8		12	8	5	3		6	21				
total missed	17	17		17	21	18	16		17		13		9	13	16	18		15					
false calls	1	0		0	0	0	0		0		1		1	3	1	0		4					

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Under the auspices of the AGARD Structures and Materials Panel R&D Cooperation Program, a round-robin NDI demonstration has been carried out. Six laboratories in four NATO countries participated in the project. The aim of the project was to determine the sensitivity and reliability of NDI procedures presently employed by the participating laboratories and to establish whether or not the procedures would be adequate for the implementation of a damage-tolerance based maintenance approach or whether improved methods are required.

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